DEVELOPMENT OF A STATISTICAL/MECHANISTIC MODEL TO PREDICT THE CONSUMPTION OF NONRENEWABLE MATERIALS IN HIGHWAY CONSTRUCTION PROGRAMS

By

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August, 1997

Chairperson: Dr. Ralph D. Ellis, Jr.
Major Department: Civil Engineering

Highway construction, as one of major consumers of nonrenewable resources, is responsible for achieving sustainability with respect to materials and structures. These materials are exhaustible. Access to these aggregate resources is increasingly limited by growing environmental regulations and permitting requirements.

This research was conducted to evaluate the current and future supplies of nonrenewable resources required to support highway construction activities, analyze past and current rates of consumption with allowances for reuse and recycling efforts. This analysis will then provide information to develop a model for predicting and analyzing future construction needs, and to outline a preliminary management approach to help achieving highway construction sustainability.

Data were obtained from highway construction projects throughout the state of Florida during the years 1986 to 1995. More than 750 activities were selected for study from a total of approximately 17 thousand activities, performed in the 10 years period were chosen. These activities involved approximately 2000 contracts between the Florida Department of Transportation and 100 contractors over the 10 years period.

CHAPTER 1
BACKGROUND AND PROBLEM STATEMENT

Introduction

The amount and type of generated waste have grown as the world population grows. Numerous waste materials result from manufacturing, sewage treatment plants, industries, households, and mining. Many of the wastes produced today will remain in the environment for a long time. While the volume of waste is continuing to grow, approval for facilities that provide proper disposal is becoming more difficult to obtain.

For many years, efforts and practices concerning landfills have been minimal. Dumpsites for municipal and hazardous waste attracted little attention and were under few controls. For many contractors, disposal of construction debris is becoming a nightmare since landfill space is decreasing, approaching its capacity, and environmental rules are toughening.

In 1979, the United States of America had more than 15,000 operating landfills. In 1988 only 6,500 were still in operation, and it is estimated that this number will drop down to half that number by the year 2000 (Dashefskey, 1993).

The reduction in landfill caused the tipping fees to rise. In Rhode Island, the tipping fees for dumping one cubic yard has risen from $6.5 in 1988 to between $15 and $20 in 1990 (Setzler, 1990). In Pinellas county, Florida, which burns 95% of its solid waste, tipping fees have risen from $15 or $20 a ton to $25 a ton (in 1987 dollars) (Tuchman, 1987). The shrinkage of landfill space, the radical increase in solid waste, and the escalation of disposal costs have all forced the public to pay attention to the ways society handles its wastes. In addition, the public is becoming more aware of the importance of conserving and preserving our valuable natural resources (Ellis, 1994). This awareness focuses primarily on recycling the wastes into useful products.

In our industrial world, unsustainable development has generated wealth and relative comfort for about twenty percent of human kind, and among the population of this industrialized nations the consciousness supporting the unsustainable economy is nearly universal. With a few important exception, the environmental-protection movement in those nations, despite its major achievements in passing legislation and mandating pollution-control measures, has not had a substantial effect on the attitudes of most people.

Today's environmental concerns center on reconciling environmental sustainability with economic development. The resulting term, "sustainable development," means that the economies of the world must meet the needs of today's generations without compromising the wealth of tomorrow's. Eleven billion people will be living on the Earth by 2050, and we must incorporate thoughts of economics with thoughts of the environment (Contanza, 1994).

Each year, the United States produces approximately 4.2 billion metric tonnes (4.6 billion tons) of nonhazardous solid wastes. Table 1.1 provides a summary of the estimated quantities and components of four major solid waste categories as well as a breakdown of the estimated annual quantities of domestic and industrial waste materials (Collins, 1994). To achieve sustainable construction, nonrenewable resources consumption must be significantly decreased; the environment (the air, the ground water, rivers, lakes and oceans) must not be polluted; nor must disposal problems or toxic wastes be created.

Materials must be recyclable and used in the most effective way possible. Structures should have long lives and buildings need to be constructed for durability and long life (Jansson, 1994). Consumption of energy during construction development should be minimized and alternatives for conventional resources should be considered.

The construction industry, as a major consumer of nonrenewable resources, is responsible for achieving sustainability with respect to the materials it employs. Approximately 2 billion tons of construction aggregate (crushed stone, sand, and gravel) are produced and sold each year in the United States (Mineral, 1984-1995). A significant percentage of this production is used for highway and bridge construction. These materials are exhaustible. The continuing demand of raw materials gradually depletes natural resources. Growing environmental regulations and permitting requirements, restrictive zoning laws, land uses, and other economic considerations increasingly limit access to these materials. The community oppositions restrict the expansion of or even force the closure of existing quarry and gravel pit operations. Such opposition creates localized shortages of construction aggregates and borrow materials in many areas. Acceptable alternatives are needed to alleviate such shortages and to conserve natural resources for sustainable development.

Research into new and innovative uses of waste materials is continually advancing. Many highway agencies and private organizations have completed or are in the process of completing a wide variety of studies and projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. Recycling is not the only acceptable way for waste management. Some other techniques are reduction of waste material at its source and reuse of the construction wastes.

For many years, our nation has assumed that the sources of domestic materials and energy are infinite. Unfortunately, the Earth's crust is not an infinite storehouse that can be readily tapped for new supplies of all kinds of mineral raw materials. All minerals are infinite quantities which can not be generated or replaced at rates comparable with their extraction; however, some minerals are more abundant than others.

The materials' life cycle is illustrated in Figure 1.1, which indicate that materials extracted can be refined and processed into bulk materials that, in turn, can be processed into engineering materials. These engineering materials are used for a certain time, and then, either recycled into a new shape for reuse or temporarily disposed of on the earth.

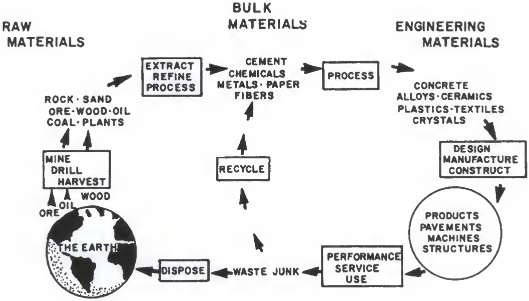
BULK MATERIALS
RAW MATERIALS
ENGINEERING MATERIALS
EXTRACT REFINE PROCESS
CEMENT CHEMICALS METALS · PAPER FIBERS
PROCESS
CONCRETE ALLOYS · CERAMICS PLASTICS · TEXTILES CRYSTALS
ROCK · SAND ORE · WOOD · OIL COAL · PLANTS
MINE DRILL HARVEST
RECYCLE
DESIGN MANUFACTURE CONSTRUCT
WOOD
OIL
ORE
PRODUCTS PAVEMENTS MACHINES STRUCTURES
THE EARTH
PERFORMANCE SERVICE USE
DISPOSE
WASTE JUNK

Figure 1.1 Life cycle of materials [after (Optimizing, 1974)].

According to 1974 calculations (Optimizing, 1974), the new materials required annually for each U.S. citizen is approximately 18,144 Kg (40,000 Lb). Figure 1.2 breaks down these amounts into several components. Mineral for use in construction and for energy constitute the major portion of these requirements. These uses of minerals are based on one-time use and then disposed. Recycling of material can significantly decrease these requirements per capita for new mineral material.

Research Objectives

The objectives of this study are as follows: 1) to perform an assessment of nonrenewable resources current rates of consumption with allowances for reuse and recycling efforts 2) to develop a model for predicting and analyzing future construction sustainability 3) to structure a preliminary construction management approach for minimizing paving operation non-sustainability.

Research Approach

The research methodology included a comprehensive review of information obtained from an electronic database

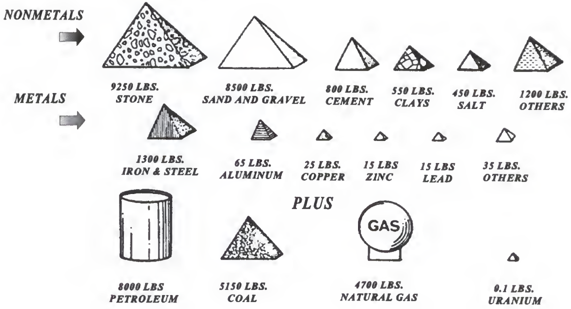

Figure 1.2 Annual quantities of materials required for every person in the United States.

which contains a wide range of published literature concerning sustainability, waste reduction, and various waste materials and the implementation of these wastes and by-products in highway construction. This database also contains information on the various methods of waste reduction and recycling which have shown promise as a substitute for conventional materials.

Other state highway agencies were contacted to obtain their current recycling efforts and evaluations of the use of recycled materials. Available natural resources quantities and their production rates were determined. In addition, an analysis of FDOT past and current rates of resource consumption were prepared. Data collected in the past phase from construction projects throughout the state of Florida is used to develop the projection of FDOT's future consumption rates and material availabilities. More than 750 activities included in approximately 17 thousand activities were reviewed. These activities are for the available 10 years data. These 750 activities were included in approximately 2000 contracts between FDOT and approximately 100 contractors.

Chapter 2 defines the meaning of sustainability and discusses the recycling techniques applied in highway construction. Chapter 3 presents data collection methods, provides a definition for natural resources in Florida, and surveys construction recycling efforts within the United States. Chapter 4 illustrates data processing and a complete analysis for the past rate of consumption of materials, and the highway construction recycling efforts within the United States. Chapter 5 contains systems analysis and modeling stages. Chapter 6 demonstrates the modeling and forecasting procedures for predicting and analyzing future construction needs of natural resources. Chapter 7 presents the model development and case history. Chapter 8 illustrates a sustainable management approach. Chapter 9 presents conclusions and offers recommendations for future researches.

CHAPTER 2
SUSTAINABILITY AND HIGHWAY CONSTRUCTION

Introduction

Sustainability can be expressed simply as leaving sufficient resources for future generations to have a quality of life similar to ours. Sustainability means that the service or product does not compete in the marketplace in terms of its superior image, power, speed, and packaging (Baldry & Golton, 1994). Instead, products must be delivered to the customer in a way that reduces consumption, energy use, distribution costs, soil erosion, atmospheric pollution, and other forms of environmental damage.

Through proper city and community design we can vastly reduce our use of natural resources and fossil fuels (Capra & Pauli, 1995). In many ways we have become a commuting society, often traveling 10 to 40 miles to our work site and then home again. The over-dependence on automobiles (and the lack of good public transportation system) creates the needs for vast highway systems which impact the environment.

The heavy reliance on gasoline fueled cars depletes resources and increases pollution from exhaust.

Societies can start out making individual homes more sustainable, followed by their communities, cities, regions, states, nation and finally the world. How can we make our homes more sustainable? First, design houses to be more energy and environmentally efficient. Use recycled building materials in construction; use passive solar energy in orientation and design; use recycled paper in the form of cellulose insulation for improving the thermal envelope and use passive heating and cooling systems where possible (Roudboush, 1992). The passive systems should be supplemented by high efficiency air conditioning, heating and water heating systems. Employ the three R's wherever possible: recycling, reusing and reducing our consumption of consumable and even major products.

With few natural resources, the highly industrialized and populous island nation of Japan tends toward sustainability by developing an economy that makes efficient use of resources. For example, according to the U.S. Department of Energy, Japan uses 7.5 million BTUs/household-degree day-year compared to the U.S. which uses 30.0 million BTUs/household-degree day-year (Trigo & Kaimowitz 1994) and (Energy, 1980-1995).

Sustainability encompasses the concept of living within the means of resources available. For the last several decades, occupants of Planet Earth, particularly those in the industrialized nations, have been living beyond the means of resources available (Wyatt, 1994). If this course continues, Earth's supply of fossil fuels and other natural resources will be depleted within the next century. In addition, Earth's environment will be damaged to such an extent that it will be unhealthy, if not unfit, for humans. The United States and other industrialized nations, particularly Japan, Sweden and Canada, have taken significant steps toward recognizing environmental concerns. However, all the clean air and water acts, reducing the chlorofluorocarbons and other environmental controls will be meaningless unless the world's population controls its appetite for fossil fuel energy (Hill & Bown, 1994).

Sustainable Development

The concept of sustainable development has many definitions. Some of these definitions are as follows:

- The sustainability of a given society means the standards of behavior which ensure that the future generation will be able to enjoy the same level of well-being as ours.

- The link between the level of current development and the ability to satisfy future needs, determined by the amount of resources that one generation passes to the next. These resources include: renewable natural resources, nonrenewable natural resources, knowledge, and traditions.

Waste can be reduced by using materials that are entirely or partially made of recycled ones. Using recycled material reduces the amount of virgin resources used, and subsequently reduces the amount of waste that ends up as landfill (D'arge, 1994).

In architecture and sustainable technology, architects see that sustainability as a set of principles must change the way the architects think and work (Barrow, 1995). Many of the principles are old and belong to the ecoconcious 1970s. The principles include such items as: preservation of wetlands, forests, animal habitats, recycling building materials, greater energy efficiency in buildings, and exploration of solar power and other alternative energy forms (Carven & Okraglik, 1994).

Architects address sustainability and environmental ideas to two new issues. First is the issue of good indoor air quality which means looking for material which are friendly to the Earth as a whole, and to the people who use and build the buildings. The kinds of building material which cause allergies should be replaced by inert ones (though recyclable) such as metals, glass, and concrete. Second, the relation between sustainability and urban design. Building an efficient building must be accessible in more sustainable ways than by long trips, consuming more fossil fuel which happens to be the world's largest pollution.

Building construction has done some research in achieving sustainability. One study showed that reducing construction wastes at its source is an effective method (Floyd, 1993). For example, constructors must be sure the correct amount of each material is brought to the site. In addition, orders such as wallboard must be consistent with room dimensions, since wallboard is available in different sizes. Purchasing pre-cut lumber can also minimize wasted resources on the construction site. Ordering oversized lumber is a waste of money and resources.

The highway construction industry has a long history of using discarded materials and by-products in the construction of highway facilities. On October 1991, the Federal Highway Administration (FHWA) and the Environmental Protection Agency (EPA) cosponsored a symposium entitled "*Recovery and Effective Reuse of Discarded Materials and By-Product for Construction of Highway Facilities.*" The symposium addressed the requirement to determine the economic savings, technical performance qualities, threats to human health, and the environmental benefits of using recycled material in highway construction. Materials that had previously been disposed of through land-fill, including old asphalt, old concrete, waste glass, slags, fly ash, roof shingles, rubber tires, incinerators, foundry sand, and motor oil showed a great potential of supporting sustainable development in highway construction.

In Canada, a study using concrete block pavements for sustainable development was conducted. The research objective was to use a pavement surfacing composed of concrete pavers that makes no use of scarce petroleum resources as do pavements with bituminous surfacing. A well-constructed block pavement has a long life and requires little maintenance. For example, when an opening has to be made in a block pavement to gain access to buried services and no jack hammers are required, then less energy is consumed (Beaty, 1996).

During 1974, the Federal Highway Administration (through its regional offices) asked state transportation and highway departments to submit suggestions on how to minimize the impact of energy and material shortages on the construction of transportation facilities in the United

States (Optimizing, 1974). As a result, eighty suggestions were submitted for informational purposes only, but no recommendations for their use were implied.

The modern industrial world is making an effort to advance sustainable development. Researchers are looking for alternative materials to substitute for conventional ones. The Powder Metallurgy is a good example to support the existence of the sustainable product in the industry.

Today's industrial development increases the demand and use of various kinds of raw materials of both metal and non-metal types. The United Nation/Economic Commission for Europe (UN/ECE) working party on engineering industries and automation has conducted three major seminars since 1990. These topics are closely related to current research (United, 1994), and they are as follows:

- Air Pollution Control in The Engineering Industries, Geneva (Switzerland), November 1990
- New Material and Their Application in Engineering Industries, Kiev (Ukraine), October 1992
- Foundry production and Ecology, Minsk (Belarus), May 1993.

The development of technical processes has been directed toward improving the quality of both metals and non-metals-based materials and reducing unnecessary losses and waste. Powder Metallurgy (PM) should be considered as one of the most effective low-waste technologies. The industries have developed a wide range of high-strength ferrous and non-ferrous PM alloys and composite materials. PM products fall into general categories including structural components, bearings, hard metals, friction metals, and electronic and magnetic materials. Structural components made from PM have many applications including automotive engine parts, household appliances, and electronic equipment.

Principles for Sustainable Construction

Sustainable construction is just one factor in creating a sustainable environment. Sustainable environment means leaving the world in a condition that allows future generations to enjoy at least the quality of life we have experienced. This could be accomplished by omitting environmental degradation and eliminating resource depletion.

Principles for sustainable construction should cover the resources to build the environment and apply to materials, energy, water, and land. The principles discussed are as follows (Kibert, 1994):

- Minimize resource consumption (Conserve)

- Maximize resources reuse (Reuse)
- Use renewable or recyclable resources (Renew/Recycle)
- Protect the natural environment (Protect Nature)
- Create a healthy, non-toxic environment (Non-Toxic)
- Pursue quality in creating the built environment (Quality)

Each principle will be introduced in terms of its relationship to sustainable construction.

Minimizing Resource Consumption

The key element of this principle is conservation. We are consuming more than we need. Conservation is the driving force which led us to address sustainability in the first place. Minimizing the use of natural resources as well as energy is essential.

Maximize Resources Reuse

Reuse already extracted materials. The reuse is simply the minimal processing of already processed items. This will indicate the reduction of required resources and energy.

Use Renewable or Recyclable Resources

Renewable resources are energy sources such as solar and wind power and materials such as wood. A wide range of material has been recycled (as described next in this chapter). A successful recycling program requires methods of collection, separation, and transportation. Technology must be available to process the used materials, prepare it for reuse, and then remanufacture it into new product. Markets for the new products must be identified and available.

Protect Nature and Environment

Considering the past negative effects on the natural environment, maybe it is time to do better than just "sustain", but to "restore" where possible (Kibert, 1994). Given the increasing demand for material, we should analyze the impact of material acquisition practices, both in mining and other energy consumption, to learn how to minimize environmental hazards.

Create a Healthy, Non-Toxic Environment

One of the consequences of successful modern industry is the production and the disposal of toxic substances. These toxics have invaded the environment and have negative effects on humans. Clearly toxic materials must be handled with care and eliminated to the greatest extent possible.

Pursue Quality in creating the built environment

Quality includes planning of communities to reduce automobile traffic and promote alternative means of travel, and provide a good quality of life. It includes excellence in designing of cities, buildings, and products as an absolutely essential component in reducing unnecessary spaces, selection of materials, reduction of consumed energy, and product longer life span.

Recycling Efforts in Highway Construction

Research into new and innovative uses of waste materials is continually advancing. Many highway agencies, private organizations, and individuals have completed or are in the process of completing a wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. These studies try to match society's need for safe and economic disposal of waste materials with the highway industry's need for better and more cost-effective construction materials (McManemy, 1992).

This chapter includes some concerns about using wastes to substitute conventional materials in highway construction. In addition, figure 2.1 illustrates recycling processes such as the hot mix asphalt method, cold in-place recycling, and hot in-place recycling. Also, current research on waste materials that has shown promise as a substitute for conventional materials is presented, focusing on new and innovative highway industry uses of waste materials and by-products.

Engineering Concern

The following concern must be addressed from the engineering viewpoint.

Properties of Asphalt Concrete

There is no doubt that the waste material will affect the engineering properties of the final product. Therefore, asphalt concrete containing waste material must be reevaluated thoroughly and carefully both in the laboratory and field.

Impact on Production

Some waste materials require a change in asphalt production processes, therefore, the production is likely to be affected.

Quality

The waste material may vary in quality, chemical, or physical properties, and thus, affect the engineering properties and quality of asphalt.

Future Recyclability

It is not well known whether the asphalt containing waste material can be effectively recycled in the future without any difficulties. For example, the result of recycling asphalt containing crumbed rubber may cause air pollution problems.

Environmental Concern

It is clear that involving some waste materials in the recycling process could produce problems due to certain hot processes connected with the recycling method.

Emission/Odor/Fumes

It is quite likely that some waste material will produce some problems with emission/odor/fumes when incorporating heat in the recycling procedure. This problem might also arise in the future when recycling the product containing the waste material.

Leaching

Components of waste material may be prone to leaching, causing pollution to rivers and ground water.

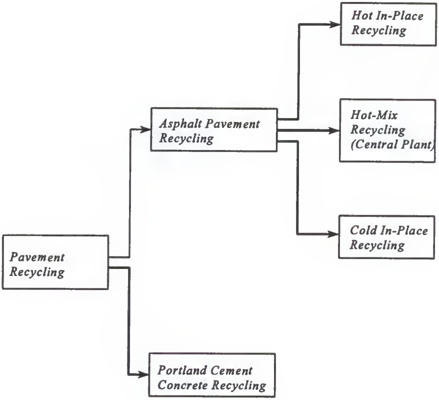
Pavement Recycling
Asphalt Pavement Recycling
Hot In-Place Recycling
Hot-Mix Recycling (Central Plant)
Cold In-Place Recycling
Portland Cement Concrete Recycling

Figure 2.1 Categorization of Pavement Recycling.

Handling and processing procedure

Some of the wastes could be hazardous and cause health risks to workers in the pavement industry.

Economic Concern

The economic properties of the waste materials play an important rule in using these by-products in the paving process. The following concerns should be addressed.

Price

Some of the waste material contribute a higher price when compared to conventional materials. For example, virgin aggregates are generally available locally at lower prices compared to waste glass which must be hauled.

Life Cycle Cost

Life cycle cost should be determined for asphalt that contains waste materials. Added waste materials may not affect the initial engineering properties, but may reduce the service life of the pavement.

Disposal Cost

If pavement containing the waste material cannot be recycled, then determining the cost of its disposal is important.

Salvage Value

At present, the salvage value of pavement that containing waste material is not well-defined.

Hot Mix Asphalt Recycling

Hot-mix asphalt (HMA) recycling is a process in which reclaimed asphalt pavement (RAP) materials are combined with new aggregate (and/or asphalt, and/or a recycling agent as necessary). This occurs in a central plant; the blending and mixing operation produce a hot-mix paving mixture. The disadvantages of hot-mix recycling compared to in-place methods are: the recycled mix generally cannot be 100 percent RAP, transporting the material to and from the central plant results in addition costs, and traffic can be disrupted for longer periods of time.

Hot In-Place Recycling

This operation is a single-step process. In this process, the existing pavement is heated, milled off, and mixed with new aggregate, modifiers, new asphalt concrete mixtures or recycled materials (Hufman & Rathbun, 1993). American Recycling and Reclamation Association (ARRA) estimated that over 18 million metric tons (20 million tons) of pavement was recycled in this manner in 1991 (Asphalt, 1992a).

Using Microwave for the Heating Process

The microwave recycling process was developed by a company in Georgetown, Texas. This method uses microwave energy to heat and recycle asphalt. With this technique, up to 100 percent of used asphalt can be recycled into new reusable blacktop. The Pennsylvania Members of the Turnpike's Environmental Action Team (EAT) have begun looking into microwave recycling of asphalt, and are convinced that microwave recycling offers a good alternative. The microwave recycling was used successfully in Texas on a resurfacing project for the Texas Department of Transportation.

The plant can produce 300 tons of recycled asphalt per hour, portable, compact, and emits no odor or environmentally hazardous smoke. In addition, the plant operates at lower noise levels than conventional plants. This method may also make economic sense. Reports from states which have used the microwave recycling process indicate that projects requiring large quantities of recycled asphalt (80 to 100 thousand tons) have shown a significant reduction in the cost per ton for asphalt material (Pennsylvania, 1992).

Cold In-Place Recycling

The cold recycling process under consideration uses a three unit train, which consists of a milling machine, an emulsion tanker, and a conventional asphalt paver. The milling machine grinds off the existing bituminous pavement and a portion of the base material. This mixture is fed into a hopper where the tanker adds an asphalt emulsion. After thorough mixing, the material is conveyed to a paver and laid in a normal paving operation (Asphalt, 1983). Following the paving operation, a vibrator roller is used for finishing. American Recycling and Reclamation Association (ARRA) estimated that over 2 million metric tons (2.1 million tons) of pavement was recycled by this process in 1991 (Asphalt, 1992b).

One of the advantages claimed for this process is that traffic can be permitted on the pavement immediately following proper operation. Another advantage of cold in-place recycling over HMA is that the cost of transporting the material to and from a hot-mix plant is saved.

Waste Materials

Waste material can be broadly described as industrial wastes, municipal/domestic wastes, and mining wastes. A general overview of waste materials (including the research work done in the past and their potential for use in pavement recycling) is given here in this chapter.

Blast Furnace Slag

Blast furnace slag is an industrial byproduct of iron produced in a blast furnace. The Bureau of Mines reported that 14 million metric tons (15.4 million tons) of blast furnace slag was sold in the United States in 1992 with a value of $99.5 million. Approximately 90 percent of this quantity was air-cooled slag, which is used primarily in road construction. Table 2.1 summarizes current uses for blast furnace slag in the United States. In some situations, blast furnace cement can provide equal or improved performance over conventional portland cement concrete. Slag cement has low heat hydration, good long-term strength gain, and high chemical resistance. Use of slag cement containing more than 80 percent granulated

Table 2.1 Air-Cooled Blast Furnace Slag Sold or Used in the United States by Use.

Use	**1991**		**1992**	
	Quantity *(1000 Ton)*	Value* *($1000)*	Quantity *(1000 Ton)*	Value* *($1000)*
Asphaltic Concrete Aggregate	1,634	$9,577.0	2,212	$13,270.0
Concrete Aggregate	1,333	$9,683.0	1,325	$9,193.0
Concrete Product	358	$2,333.0	469	$2,863.0
Fill	855	$3,950.0	1,229	$5,328.0
Glass Manufacture	W	W	W	W
Mineral Wool	449	$3,056.0	745	$4,872.0
Railroad Ballast	221	$1,288.0	177	$829.0
Road Base	5,339	$30,282.0	5,894	$31,183.0
Roofing Shingles	68	$771.0	70	$844.0
Sewage treatment	W	W	W	W
Soil Conditioning	W	W	W	W
Other**	633	$5,455.0	665	$6,238.0
Total* **	**10,889**	**$66,393.0**	**12,697**	**$74,620.0**

* Value Based on Selling Price at Plant

** Includes ice control and miscellaneous uses

*** Data may not add to totals because of rounding

W Withheld; Data are included with "Other."

Source: U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1992.

blast furnace slag can, however, increase the time needed to attain design strength.

A recent innovative use study examined the effects of slag on roller-compacted, no-slump, lean concrete mixes. Several agencies have also used air-cooled, non-granulated blast furnace slag as an aggregate in hot mix asphalt (HMA) pavements, as a base or sub-base material, as an embankment material, and in snow and ice control (Pratt, 1992).

Steel Slag

Steel slag, a by-product of the steel-making process, contains fused mixtures of oxides and silicates, primarily calcium, iron, and magnesium. Steel slag contains significant quantities of iron; its highly compressed void structure results in a very dense, hard material. In 1992, 6.9 million metric tons (7.6 million tons) of steel slag was sold in the United States at a total value of $21.9 million. Table 2.2 summarizes current uses for steel slag in the United States. Current researches concentrate on using steel slag as aggregate in hot mix asphalt. One of the Pennsylvania Department of Transportation's studies found that bituminous mixtures containing steel slag exhibited high stability, high skid resistance, and longer bear retention resulting in easier compaction. However, its use

Table 2.2 Steel Slag Sold or Used in the United States.

Use	**1991**		**1992**	
	Quantity (1000 Ton)	Value* ($1000)	Quantity (1000 Ton)	Value* ($1000)
Aspaltic Concrete Aggregate	1,085	$4,617.0	903	$4,272.0
Fill	828	$2,374.0	1,037	$3,067.0
Railroad Ballast	186	$585.0	224	$772.0
Road Base	3,238	$10,625.0	2,400	$7,256.0
Others**	1,623	$5,531.0	2,256	$6,064.0
Total* **	**6,959**	**$23,732.0**	**6,857**	**$21,972.0**

* *Value Based on Selling Price at Plant*

** *Includes ice control and miscellaneous uses*

*** *Data may not add to totals because of rounding*

Source: U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1992.

as an aggrade is not presently cost-effective given its high asphalt absorption rate.

Glass and Ceramics

Glass contributes approximately 7 percent of the total weight of U.S. municipal solid waste, or about 12 million metric tons (13.2 million tons). Approximately 20 percent of this glass is being recycled, primarily for cullet in glass manufacturing.

The use of waste glass in asphalt (glasphalt) is not new. It was originated more than twenty years ago through experimental work at the University of Missouri-Rolla. A survey was performed on the use of waste glass in the city of New York. Asphalt mixes containing up to 15 percent by weight of glass were produced and used in New York city during 1990 and 1991 paving seasons (Chesner, 1991).

At least ten state highway agencies have experimented with glass in highway construction. Current research concentrates on using glass as aggregate in asphalt pavements, pipe bedding, and as addition to soil embankments. New Jersey Department of Transportation (NJDOT) specifications allow the substitution of up to 10 percent glass (by weight) for aggregate in asphalt base courses.

Ceramic waste consists of china and porcelain from factory rejects, discarded housewares and plumbing fixtures. In California, crushed porcelain from used toilets has been used as an unbound base course aggregate for the roadway near Santa Barbra. Results showed that crushed porcelain met or exceeded quality requirements for concrete aggregate.

Engineers have speculated about glascrete since the 1970s, but it has never been subjected to intensive laboratory testing. With gravel pits closing and aggregate quarrying and shipping costs rising, interest has increased. In 1993 alone, New York City collected 27,000 tons of mixed waste glass and poured it into glasphalt, 90% asphalt and 10% glass.

To make glascrete viable, research must be done to eliminate the reaction of silica in glass with the alkali in cement that may weaken glascrete over time.

Scrap Tires

It is estimated that 285 million tires are discarded annually in the United States. Of these, about 55 million are reused (resold), and about 42 million are diverted to various alternative uses such as fuel for generating power and additives to asphalt pavement (Huffman, 1993). The use of crumb rubber to modify asphalt cement has been developed over the past 25 years. Crumb rubber is primarily used in Hot Mix Asphalt (HMA) mixed by two processes:

- The wet process blendes crumb rubber with asphalt cement prior to incorporating the binder into the project. This modified binder is called "asphalt-rubber". Approximately 18 to 26 percent of crumb rubber by weight of asphalt cement is reacted with asphalt cement at 190 to 218° C for one to two hours.
- The dry process includes mixing the crumb rubber with aggregate before incorporating the asphalt cement. About 3 to 5 percent of coarse rubber particles by weight of aggregates are generally used. The amount of rubber that can be used in the dry process is approximately 2 to 4 times that used in wet process (Swearingen, 1992).

One of the researchers interested in adding crumb rubber to asphalt cement has spent the last 17 years experimenting with the product under all sorts of weather and traffic conditions (Michael, 1995). He began using asphalt rubber pavement in the snowy regions of the high Sierras. One section near Strawberry, California, is "still performing" after 10 years. In the Donner Pass area of I-80 between Sacramento and Reno, after nine years, the pavement showed "some rutting" in areas where tire chains were used.

During this period low maintenance was required and the pavement proved highly cost-effective.

Although in some instances the asphalt rubber pavement did not justify its extra cost, generally speaking it proved superior to conventional asphalt in the long run. Its low maintenance and long wear more than justify a cost differential which has decreased with additional use of rubberized asphalt. In California, conventional asphalt costs about $ 110 per ton compared to $ 260 for asphalt rubber (Collins, 1994). California pavement crews are now using coarser mixes in asphalt pavement with more tire crumbs in the binder. In other states, such as Arizona, the pavement has also proven to provide better traction and reduce traffic noise by as much as 50%.

Plastics

Plastics comprise more than 8 percent of the total weight of the municipal waste stream and about 12 to 20 percent of its volume. In 1992, approximately 14.7 million metric tons (16.2 million tons) of plastics were discarded in the United States; only 0.3 million metric tons (0.33 million tons) or 2.2 percent were recycled. Current research on the use of recycled plastics in highway construction is wide and varied. The use of virgin polyethylene as an additive to asphaltic concrete is not new; however, two new processes also use recycled plastic as an asphalt cement additive (Collins, 1993).

Recycled plastic is made into pellets and added to asphalt cement at a rate of 4 to 7 percent by weight of binder (0.25 percent to 0.50 percent by weight of total mix) (Zhong & Woodman, 1993).

Michigan State University is looking into the use of recycled plastic in portland cement concrete. In this study, recycled, high-density polyethylene (HDPE) was used to replace from 20 to 40 percent of fine aggregate by volume (7.5 to 15 percent by total volume) in a lightweight concrete mix. Compressive strengths were reduced when HDPE was used. Overall flexural strengths remained fairly constant and the impact resistance of the concrete, which can be related to flexural toughness, increased.

Many agencies and private companies have been experimenting with the use of recycled plastic for items such as guardrail posts and block-outs, fence posts, noise barriers, sign posts, and snow poles.

The Federal Highway Administration has approved the use of a guardrail offset block made of 100 percent recycled wood and plastic. Although the product's initial cost is currently higher than for conventional block material, it is believed that the post will resist damage and deterioration better than conventional materials, thereby, reducing overall life-cycle cost.

Construction and Demolition Debris

It is estimated that at least 20 to 30 million tons per year of construction and demolition (C&D) debris are generated in the United States (Lauritzen, 1993). C&D debris consists largely of wood and plaster, but also includes concrete, glass, metal, brick, shingles, and asphalt (Schroeder, 1994). Portions of this debris that are reclaimed, crushed, and processed into aggregate include concrete, bricks, glass, and old asphalt (Gorle & Saeys, 1988). Recycling of C&D debris is done regularly at numerous processing locations around the country, mainly in large metropolitan areas. To be marketed effectively, the processed material must be free of deleterious components such as wood drywall and plastic, and must be capable of meeting gradation and other aggregate quality requirements (Kawamura & Tori, 1988) and (Spencer, 1989).

A survey over the 50 states in the United states showed that at least five state highway agencies have been investigating the possible use of rubble from C&D debris as a highway construction material. Three states are investigating its potential for use as an embankment borrow source. Two states are evaluating this material as an unbound base course aggregate, and one state is examining the possibility of using it as an aggregate in asphalt paving (Collins, 1994). Three states have indicated some limited use of C&D debris. Two states have used the rubble portion as embankment borrow. One other state has used this material as an aggregate base and a concrete coarse aggregate. Construction and demolishing debris has been used in local road construction.

Reclaimed Asphalt Pavement

Based on extrapolations from state agency questionnaire responses, approximately 46 million metric tons (50 million tons) of asphalt paving material are currently being milled annually. Much of this material is returned to producers' yards for use in paving mixes. About 20-50 percent of all the milled asphalt paving material is able to be recycled into hot-mix asphalt paving mixtures (Pukman & Henrichsen, 1988). Reclaimed asphalt pavement (RAP) can be recycled into hot mixes, cold mixes, or in-place mixes (Waller, 1994). RAP can also be used in other highway uses, such as in unbound aggregate base and subbase, stabilized base course, and shoulder aggregate (Gross, 1980).

At least 36 states have been or are now performing research on various uses for RAP. This includes 32 states that are investigating the recycling or reuse of RAP in new asphalt paving; 10 states evaluating RAP in aggregate base or subbase; 3 states studying RAP use in stabilized base course; and 1 state that is evaluating the use of RAP as a coarse aggregate in concrete mixes. At least three states are planning research into uses for RAP. Also, there are at least three research projects investigating uses for RAP being conducted at the university level.

Reclaimed Concrete Pavement

The American Concrete Pavement Association (ACPA) has indicated that approximately 328 kilometers (200 miles) of concrete pavement are being recycled each year. Assuming these pavements are two lanes wide and 25 cm (10 inches) thick, and using a recovery factor of 75 percent, then approximately 5450 metric tons (6000 tons) of concrete can be reclaimed from every mile of concrete pavement (Lane, 1982). This calculation indicates that roughly 2.6 million metric tons (2.9 million tons) of reclaimed concrete are being recycled annually. Generally speaking, recycled coarse aggregate (material larger than 3/8 inches) is more suitable than recycled fine aggregate (material smaller than 3/8 inches), especially when reused in concrete mixes

(Lloyd, 1996). Reclaimed concrete pavement (RCP) is also useful as a base course aggregate, in cement-treated base, as an asphalt paving aggregate, as embankment base material, and as riprap (Mackay & Emery, 1993).

Within a few years, recycled concrete aggregate was being used in asphalt-wearing surfaces (Sano & Yagishita, 1993). The FHWA coordinated research among state highway agencies to evaluate the suitability of RCP as an aggregate source in concrete mixes. This work included laboratory studies, mix design testing, and performance evaluation of RCPs. These studies have proven that recycled concrete aggregates produce strong, durable concrete suitable for use in pavements.

Over the years, the recycling of concrete pavements has become more cost competitive with the development of improved methods and equipment for breaking concrete pavements, removing the steel from the broken concrete, and crushing slabs with reinforcement (Green, 1988). In many instances, concrete pavement recycling is a viable alternative to complete construction, concrete pavement rehabilitation, or an overlay of an existing, deteriorated pavement. Existing concrete pavement must be considered as a resource that can and should be recycled or reused in some application (much in the same way as asphalt pavement recycling is now commonly practiced).

Fly Ash

The primary components of coal fly ash are silicon dioxide, aluminum oxide, iron oxide, and calcium oxide. Approximately 45 million metric tons (49.6 million tons) of fly ash are produced annually in the United States. About 34 million metric tons (37.5 million tons) are disposed of either onsite or in state-regulated disposal areas; 11 million metric tons (12.1 million tons) are reclaimed (Schroeder, 1994).

The leading use of fly ash is a partial replacement for portland cement in ready-mix concrete or as a component of the blended portland-pozzolan cement. In 1988, a study was undertaken to evaluate the use of fly ash as a component in a stabilized aggregate base course. Laboratory investigations determined that the optimum mix was a composite of 84 percent dense-graded aggregate, 11 percent fly ash, and 5 percent hydrated lime. After three years of service, the experimental section is outperforming the conventional section; and, the amount of rutting is significantly lower in the experimental section than in the control section. Aside from minor reflective cracking associated with base shrinkage, the experimental section has performed well.

A survey of all 50 states indicates that 35 state highway agencies are now or have been conducting research on different uses of fly ash. A total of 30 states are investigating the use of fly ash as a cement replacement in portland cement concrete. Six states are considering fly ash as an embankment material. Six states are evaluating fly ash in stabilizing base course applications. Five states are conducting research into the use of fly ash in soil subgrade stabilization. Four states are evaluating fly ash as a mineral filler in asphalt (Collins, 1994).

Sulfur Binder

Sulfur has been used experimentally as a pavement binder in three different ways. In sulfur-extended asphalt, a significant amount of the asphalt binder ordinarily used in pavement construction is replaced with elemental sulfur. Asphalt can dissolve from 14 to 19 percent by weight of sulphur. Additional sulphur is dispersed into the asphalt as micron sized particles (Gross, 1980).

Sand-asphalt-sulfur is a hot mix paving material made of sand, bitumen, and sulfur. A small portion of the sulfur, which represents 8 to 14 percent of the total mix by weight, is dissolved in the bitumen while the bulk of the molted sulfur acts as a structural agent (Gross, 1980).

In plasticized sulfur mixes, asphalt cement is replaced with sulfur containing 30 to 40 percent by weight of plasticizers or chemical modifiers that offset the brittleness of elemental sulfur.

Carpet Fiber Waste

The carpet industry in the United States produces about 1 billion square meters of carpet per year. Of this, approximately 70 percent is used to replace existing carpet; this translates into 12 million metric tons (13.2 million tons) of carpet waste produced annually. Additional wastes produced by the carpet-making industry increase the total amount of waste fibers to an estimated 2 million metric tons (2.2 million tons). Several research efforts are addressing ways to include these waste fibers in both asphalt pavements and portland cement concrete (Gordon & Kennedy, 1993).

To determine the effectiveness of using recycled fibers from old carpet for concrete reinforcement, fibers were mixed with concrete in a standard drum mixer at a rate of 2 percent by volume. Compressive and flexural strengths were compared with concrete free of fibers and concrete containing 0.5 percent. The results indicated that using 2-percent carpet waste in the mix had no appreciable effect on flexural strengths, but did markedly decrease 28-day compressive strengths (Wang & Zuriek, 1993). However, some experiments showed that the addition of carpet wastes can be effective in increasing the concrete's energy-absorption abilities.

Another research effort in this area focused on the use of waste nylon fibers to reduce plastic shrinkage cracking. Laboratory tests on a limited number of samples indicated no significant difference from conventional concrete in terms of compressive or flexural strength. Results from field testing indicated that the addition of waste nylon fibers into portland cement concrete panels can reduce plastic shrinkage cracking by about 90 percent.

Incinerator Ash

The United States has around 140 thermal reduction facilities with the ability to burn at least 50 tons of solid waste per day (Collins, 1994). These facilities burn nearly 26 million metric tons (28.6 million tons) per year of municipal solid waste (MSW), generating roughly 7.8 million metric tons (8.6 million tons) of incinerator ash or residue. It was estimated that about 10 percent of this ash is fly ash and the remainder is bottom ash (Collins, 1994). Bottom ash typically meets the environmental standards for the toxicity characteristics leaching procedure. Fly ash, however, usually contains a high percentage of heavy metals such as lead and cadmium which exceed regulatory limits.

Several studies have focused on using incinerator residue as a partial aggregate substitute in an asphal concrete base course. Results showed that this use resulted in performance equal to that obtained from conventional asphalt pavements. A recent research involved the use of combined MSW ash as an aggregate in stabilized and unstabilized bases and sub-bases (Passto, 1993). Results indicated that cement-treated MSW ash can produce increased density and compressive strengths over conventional soil cement. However, leaching tests on the cement-treated MSW ash showed levels of copper, cadmium, and lead that may exceed the legal drinking water standards of some agencies.

Roofing Shingle Waste

Between 8 and 12 million metric tons (8.8 and 13.2 million tons) of roofing shingles are manufactured each year in the United States. Since approximately 65 percent of these shingles are used for reroofing, between 5 and 8 million metric tons (5.5 and 8.8 million tons) of old waste shingles are produced annually. In addition, between 400,000 and 900,000 metric tons (440,000 and 990,000 tons) of waste are produced annually from the manufacture of roofing shingles.

Minnesota has conducted several projects on the use of roofing shingles in Hot Mix Asphalt (HMA) pavements.

Findings from a study on their use in dense-graded mixes indicated that the addition of roofing shingle waste can result in a reduction in optimum neat binder content, enhance the ability to become dense under compaction, and increase the plastic strain component in permanent deformation measurements. Cold tensile strengths were also reduced, but the impact on the corresponding strains was dependent on the type of shingle waste and the grade of asphalt cement. This finding could indicate that HMA's potential for thermal cracking could be reduced by adding roofing shingle wastes.

The Minnesota Department of Transportation completed a project in 1991 that used from 5 to 7 percent asphalt shingles by weight of mix. The shingles were ground to a uniform consistency resembling coffee grounds and were added to a drum mix plant as if they were recycled asphalt pavement. No construction problems were noted; further, there have been no problems reported regarding pavement performance.

Petroleum Contaminated Soil

It is estimated that there are 0.8 to 1.2 million leaking underground storage tanks (UST) in the United States. Most of these leaking tanks contain petroleum by-product such as gasoline and fuel oil. Leaking petroleum products from USTs contaminate soil and move to contaminate ground water (Meegoda & Mueller, 1993). In 1984, US congress regulated leaking of USTs. Now almost all the fifty states require removal and proper disposal of petroleum-contaminated soils (PCS) to prevent further contamination of ground water. Excavated PCS are disposed using one of two methods: Disposing in landfills and disposing as construction material in highway industry.

Most states encourage the removal of tanks after 25 years of service. The removal of a leaking tank generate approximately 37 to 58 cubic meter of contaminated soil (Meegoda & Muller, 1993).

Wood Lignin

One of the promising approaches is to use wood lignin as a mean of reducing the dependence of the use of asphalt cement in paving operations. Lignin is a cementitious material that binds fibers together in wood. Lignin derivatives are a major by-product of the paper making industry. Aside from being one of the nation's more valuable renewable resources, lignin is one of the few materials which is expected to be in large supply (Terrel, 1980).

In past years, highway soil stabilization has been one important use for wood lignin. In fact, from the late

1920's until the present, significant quantities of spent lignin have been sprayed on roads both for the purpose of making a hard durable surface and for dust reduction. In areas of low rainfall, spent lignin treatments have produced durable roads with less tendency to form chuck holes than those surfaced by an oil treatment. Lignin have also been used together with asphalt and road oils to produce emulsions.

One basic difficulty of using lignin as a substitute for asphalt is the fact that lignin sulfonates in spent liquors are soluble in water, and thus, when a dried road surface or base becomes wet with rain, the lignin sulfonates dissolve and lose their utility as a road binder. According to the current approaches for using lignin sulfonates as substitutes for asphalt, it is desirable to bring about insolubility or limited solubility in the lignin sulfonates and thereby avoid the problems created by water.

Rice Husk Ash

Rice husk, an agricultural waste, contributes about 20 percent of the 300 million metric tons (330 million tons) of rice produced annually in the world. Due to environmental concerns and the need to save energy and resources, efforts have been made to burn the husks at a controlled temperature and atmosphere, and to utilize the ash as a cementing material (Zhang & Malhorta, 1995).

Present investigations concentrate on the use of rice husk ash (RHA) as a cement replacement material in concrete. A recent research was conducted on air-entrained concrete mixtures. Mixtures were made to evaluate the effect of the percentage of RHA as cement replacement and water-to-cementitious materials ratio on the properties of fresh and hardened concrete. The same investigation incorporated a control portland cement concrete mixture.

Investigation results proved that RHA is a highly reactive pozzolanic material and can be used as a supplementary cementing material to produce high-performance concrete. The compressive strength of the concrete containing up to 15 percent of the RHA was higher than that of control portland cement concrete. Results also showed that the RHA concrete had higher compressive strength at ages up to 180 days compared with that of the control concrete. The RHA concrete showed excellent performance under freezing conditions. The RHA concrete had slightly longer setting times than those of control concrete.

Chat Wastes

The U.S. Environmental Protection Agency (EPA) is developing a regional policy on chat that will encourage its continued use as a resource in road construction. Chat is the waste rock that is left after the host rock is milled to free the lead and zinc ores. At one time, there were mountains of chat in the Tri-State Mining District. More than 80 percent of it has been shipped out, but millions and millions of tons remain (Kennedy, 1995).

The chat piles contain traces of lead and other heavy metals in varying amounts. Some piles have been reworked and are relatively free of lead, while others are described as "hot", because of their elevated lead content. Given the lead factor, EPA recommends that chat should not be placed on residential driveways, public streets and playgrounds (Kennedy, 1995). It also should not be used in the crawl space below a house. The EPA says one of the best uses for chat is as an ingredient in concrete or asphalt. Another good use for chat is roadbed construction. When used in those ways, the lead is encapsulated and does not pose a risk of exposure to humans.

Phosphogypsum

The potential of phosphogypsum as a low-cost, high-strength substitute for limestone and other aggregates in road-building is encouraging aggregate deficient states along the Gulf Coast to test the controversial fertilizer byproduct in base and surface road mixtures (Phosphogypsum, 1989) and (Alexander, 1983).

Fertilizer producers are under pressure from state and federal authorities to find new ways to dispose of the nearly 44 million tons of phosphogypsum they generate each year (Robert, 1985). Landfills in Florida and Louisiana have turned to academicians to find new ways to use the material (Report, 1985). Highway construction is at the top of their list (Boyle, B., 1990).

At the Florida Institute for Phosphate Research in Bartow, for example, researchers are testing the structural and environmental aspects of the material on two small stretches of county highway in central Florida. According to the Institute's research team for chemical processes, the industry participants know in reality there's no danger from radiation (Engineering, 1987).

CHAPTER 3
DATA COLLECTION

Introduction

Measuring the consumption of limestone as a natural resource in the highway construction is essential to developing a prediction model, as well as achieving a management approach for sustainable construction. The structures of the model and its prediction of future consumption rates, though future needs of natural resources, are based upon historical consumption data. Careful consideration must be given to many issues in data collection, since both the validity of the model and the accuracy of prediction depend directly on the input data.

Definition of Available Construction Resources

Limestone will be the only mineral resources considered for modeling purpose in this research. Limestone underlies all of Florida, but in many parts of the state it is covered by sand and clay which form the land surface. Limestone in Florida is divided into the following types:

Key Largo limestone, Miami Oolite, Coquina, Ocala limestone, Swanee limestone, and Tampa limestone.

Most of the limestone aggregates produced in Florida are crushed for use in highway construction, as an aggregate in concrete, as a soil conditioner in agriculture, in Portland cement, as railroad ballast, as riprap, as building stones, in chemical industries and other miscellaneous applications (Puri, 1964)

Limestone is used on a wide scale in highway construction. For example, limestone is used in base, embankment, asphalt concrete aggregate, Portland cement concrete, and in the production of Portland cement.

Highway Construction Rates of Consumption

Due to expanded highway paving operations, raw materials are systematically converted into waste, as a by-product in the construction process. In most cases, depletion of these wastes is slower than nature can absorb resulting in contamination, environmentally-regulated wastes, and subsequent costs. Highway construction typically consumes tremendous amounts of raw materials, and produces huge quantities of wastes. Therefore, consumption should be optimized through the use of models. To consider recycling as a part of the highway construction process, we must study the types of material to be used and methods of implementation.

In this research, material consumption rates are from Florida Department of Transportation's construction contract history. The objective of this research step is to collect and analyze data to assist in understanding the responsible management problems of sustainable methods of handling construction and demolition waste (C&D). To identify past and current quantities used in highway construction, data were extracted from the construction contract history of Florida Department of Transportation for the last ten years by the researcher. Some of the data was collected electronically from the FDOT mainframe, and the rest from document copies. Data from FDOT is used in statistical analysis as well as in model development in this research.

It was noted that about five percent of yearly activities account for approximately forty percent of the total expenditure for that year (as shown in Figure 3.1). As an example, activities that have the higher values in highway construction are: asphalt concrete pavement including its courses, and cement concrete pavement. These items are considered in this research.

It is important to monitor the total expenditures through the defined research period. The Florida Department of Transportation spends around one billion dollar in construction and maintenance of roads every year. Analyzing this data will provide a prediction for future sustainability. The total expenditures for FDOT over a 10 year time period is shown in Figure 3.2.

The research data is obtained from highway construction projects throughout Florida for the years 1986 to 1995. More than 750 activities selected from a total of approximately 17 thousand activities were chosen from the available ten years of data. These activities occurred during about 2000 contracts between Florida Department of Transportation and approximately 100 contractors

Construction Recycling Efforts

For the purpose of recycling and waste management evaluations, all the Departments of Transportation (DOTs) within the U.S. were contacted to obtain their current practice. Questions were asked about which materials are being used in their construction programs, the effect of adding waste materials to overall costs, and the effect of adding wastes to engineering performance. The obtained data is used to understand the potential of using waste materials recycling to reduce the consumption of nonrenewable resources, and will provide a feedback in the model development. Surveys are shown in Appendix A.

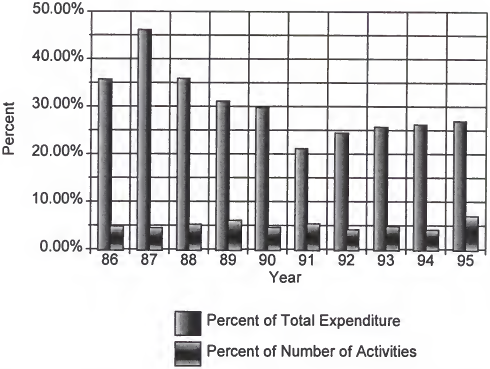

Figure 3.1 Selected activities making use of limestone versus total number of activities used in highway construction.

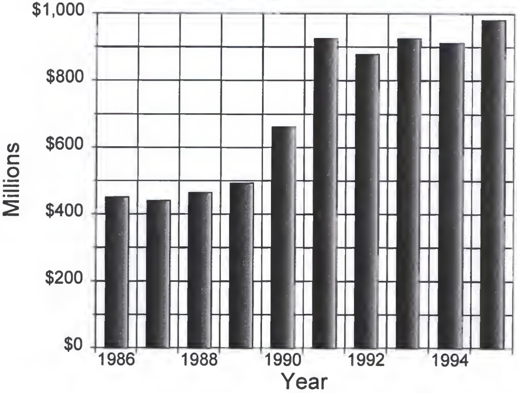

Figure 3.2 FDOT total expenditures for the years 1986 to 1995.

CHAPTER 4
DATA PROCESSING

Introduction

Data processing and management are important to consider during the preparation of the rate of consumption model. This chapter provides qualifying and quantifying data in order to conduct a complete analysis of the construction recycling efforts within the United States as well as past consumption rate of materials within the state of Florida.

Construction Recycling Efforts

Questionnaires were sent to the highway agencies in all fifty states to obtain information on the state's practice in regard to the use of waste materials and by-products in highway construction and maintenance. The survey requested basic information from each state concerning the acceptability of certain waste materials in highways, the actual use of specific waste material in construction, the result of adding of each waste material on the overall engineering performance, and the economic effects of these additives. The highway agencies in 35 states responded to this questionnaire. The findings from these questionnaires are provided in this chapter.

Reclaimed Asphalt Concrete

Approximately 48.5 million metric tons (50 million tons) of asphalt paving materials are currently being milled annually in United States. Much of this material is returned to producers' yards for use in paving mixes. Based on data obtained from state agency questionnaire responses, all the 35 responding states have been or are now performing research on various uses of reclaimed asphalt concrete (RAP). This includes 11 states that are investigating or using RAP in asphalt concrete pavement in the friction course. A number of 32 out of 35 states are using RAP in the Structural course. One state reported its experience in using RAP as aggregates in Portland cement pavement.

RAP is used by several states in the pavement base and the subgrading. The results show that 23 states are using RAP in the pavement base, and 6 states are using it as subgrading.

The questionnaire also obtained information about the states' agency evaluation for RAP in term of economics and engineering performance. Compared to conventional materials, 28 states discovered that RAP costs less, and 6 reported that it is of equal cost. The engineering performance evaluation showed that RAP is better in 1 state, equal in 32 states, worse in 1 state, and 1 state is still in the evaluation process.

Fly Ash

Fly ash is a by-product resulting from coal combustion for power generation. There are approximately 420 coal-burning power plants located in 44 states. These plants produce around 44 million metric tons (48 million tons) of fly ash.

The survey indicated that 31 state highway agencies are now or have been performing research on various uses for fly ash. Of these, 28 states are investigating the use of fly ash as a cement replacement in portland cement concrete. Ten states are conducting research into the use of fly ash in subgrade stabilization. Nine states are using fly ash in pavement base. Also, six states agencies are including fly ash in asphaltic concrete pavement; three are adding fly ash to the friction course; and the other three are using it in the structural course.

The economical evaluation of fly ash showed that 20 state agencies described fly ash as a more economical material compared to raw materials. Nine states indicated that fly ash is of equal cost, and 2 states implied that it is more costly. The engineering performance evaluation showed that fly ash is better in 10 state, equal in 19 states, and worse in 2 states.

Scrap Tires

It has been reported that approximately 235 million tires are discarded annually in the United States, generating about 1.8 million metric tons (2 million tons) of scrap rubber.

The survey found that 18 state highway agencies have conducted research on one or more ways of reusing scrap tires in highway construction, mainly as additives to the asphalt mixes. Seven states are evaluating scrap tires in the friction course of asphaltic concrete pavement, and nine states are implementing it in the structure course. Five states are evaluating the use of the scrap tires in the subgrade.

Having investigated the economical aspect, 17 state agencies consider it uneconomical; 1 state is still undecided; and no one considered it economical. Of the 18 states using scrap tires, 2 considered its performance successfully; 8 reported that its comparability to the conventional materials; 7 states believed its has a worse performance; and 1 state is still undecided.

Blast Furnace Slag

The total of 14 million metric tons (15.5 million tons) of furnace slag are sold annually in the United States.

Many state highway agencies have researched various uses for blast furnace slag. The survey showed that 15 state agencies have used it in substituting aggregates in highway construction. About 9 states are monitoring its use in Portland cement concrete, and 8 states are using it in pavement base. Fourteen states are also investigating the use of furnace slag in asphaltic concrete pavement; with seven states monitoring its use in friction course, and the other 7 states in structural course.

The survey showed that 1 state considers furnace slag more costly; 11 states evaluated it as of equal cost; and 3 states indicated that furnace slag is economical. Of the 15 states using furnace slag, 4 considered its performance successfully; 9 reported that its comparability to the conventional materials; 1 states believed its worse performance; and 1 state still undecided.

Waste Glass

Approximately 11.4 million metric tons (12.5 million tons) of glass are included in discarded wastes annually. Waste glass has potential applicability as a fine aggregate in asphalt concrete. At least 10 state highway agencies have researched possible use of waste glass in highway construction. One state highway agency indicated the use of waste glass in the friction course of the asphalt concrete pavement. Four states are using waste glass in asphalt concrete pavement-structural course; 5 state agencies are involving it in pavement base; and, five states use it in subgrade.

The survey showed that 4 states consider waste glass more costly; 4 states evaluated it as of equal cost; and, 2 states indicated that waste glass economical. All 10 states using waste glass reported that its performance is comparable to the conventional materials.

Steel Slag

Steel slag is formed when lime flux reacts with iron ore in a steel furnace. In 1989, about 7.1 million metric tons (7.9 million tons) of steel slag were produced in the United States. The survey indicated that the total of 9 state highway agencies are using steel slag in highway construction. This includes 7 states that are investigating or using steel slag in asphalt concrete pavement in the friction course. One state is using steel slag in the structural course. One state reported its experience in using steel slag as aggregates in Portland cement pavement. Steel slag is used by 2 state highway agencies in the pavement base and the subgrading.

The economical evaluation of steel slag showed that 2 state agencies described it as a more economical material compared to raw materials. Four states indicated that it is of equal cost, and 2 states implied that it is more costly. The engineering performance evaluation showed that steel slag is better in 5 state, equal in 2 states, and worse in 2 states, when compared to conventional materials.

Bottom Ash

Bottom ash is one of the resulting by-products from coal combustion in power generation. About 12.7 million metric tons (14 million tons) eof bottom ash are produced annually in the United States.

The survey of the 35 responses found that 7 state highway agencies have conducted research on one or more ways of reusing bottom ash in highway construction, mainly as aggregate in the asphalt mixes. Two states are evaluating bottom ash in the friction course of the asphaltic concrete pavement, and one state is implementing in the structure course. One stat is evaluating the use of bottom ash as an additive to protland cement pavement concrete; four states are investigating bottom ash in the pavement base; and, two state agencies are experimenting with the subgrade.

The economical evaluation of bottom ash showed that 2 state agencies implied that it is more costly; three states indicated that it is of equal cost; one state found that it is more economical material; and one state is undecided. The engineering performance evaluation showed that bottom ash is equal in 5 states; worse in 1 state; and undecided in one state.

Mining waste

Approximately 1.6 billion metric tons (1.8 billion tons) of mineral processing wastes are generated in the United States every year. Mining wastes have been used in highway construction in 7 different states. Four states have used mining wastes in the friction course of asphalt concrete pavement. Four states have investigated mining waste in the structural course. Two states are inspecting its use in portland cement concrete; 2 states are using it in pavement base; and 3 states in the subgrade. The survey illustrated that 1 state considers mining waste more costly; 3 states evaluated it as of equal cost; and 3 states indicated this use of mining waste is economical. Of the 7 states that are using mining waste, 2 considered its performance successfully; 4 reported that its comparable; and 1 state believed its worse performance when compared to conventional materials.

Building Rubble

At least 18 to 27 million metric tons (20 to 30 million tons) of building rubble and construction and demolition debris (C&D) are generated yearly in the United .

The result of the questionnaire showed that six state highway agencies have been researching the possible use of building rubble as a highway construction material. Three states are investigating its potential for use as pavement base. Four states are evaluating this material as a filling material in the subbase.

The evaluation analysis showed that the building rubble is believed to be of equal cost in 1 state, and less cost in 5 states when compared to regular materials. From the performance point of view; five states indicated that building rubble is equal; and 1 state indicated its worse performance.

Roof Shingles

Approximately 9 million metric tons (10 million tons) of roof shingle waste are generated annually in the United States. This quantity is generated as scrap and leftover materials at shingles manufacturing operations, and some other quantities are generated by roofers and demolition contractors.

According to questionnaire responses, six state highway agencies are investigating the use of roof shingles in highway construction. Three states have used roof shingles in the friction course of asphalt concrete pavement. Five states have investigated the use of roof shingles in the structural course.

For the purpose of cost analysis, all six states consider roof shingles as of equal cost as conventional materials. In addition, all the 6 states, are using roof shingles, reported its comparable performance.

Plastics

The total amount of plastics waste reaches 13 million metric tons (14.4 million tons). The survey results indicated that at least three states have used plastic waste in some type of highway application. All responding states used plastic waste as an asphalt cement modifier in the structural course.

The survey recorded that 2 states consider plastic waste as more costly, and 1 state indicated that it is economical. Of the 3 states that using plastic wastes, 1 considered its performance successfully; 1 reported that it is comparable; and 1 state is undecided.

Reclaimed Portland Cement Concrete Pavement (RCP)

The American Concrete Pavement Association (ACPA) has estimated that approximately 5400 metric tons (6000 tons) of concrete can be reclaimed from every mile of concrete pavement. This indicates that approximately 2.6 million metric tons (2.9 million tons) of reclaimed concrete are being recycled annually. Recycled course aggregate is suitable when reused in concrete mixes, as a base course aggregate, as an asphalt paving aggregate, as embankment base material, and riprap (Yjarason, 1989).

Responses to the questionnaire indicated that 3 states are performing, or have performed, research into the use of RCP aggregate in highway construction. Two state highway agencies are investigating the use of RCP in the structural course. Three states are performing research of sing RCP as an aggregate in Portland cement pavement, and two states are considering RCP as an aggregate in pavement base.

As for the cost analysis, one state considers RCP as equal the cost of conventional materials, and 2 states indicated that it is more economical. All 3 states that are using RCP reported its comparable performance.

Used Motor Oil

Approximately 10 billion liters (2.6 billion gallons) of lubricating oil are sold in the United States. About 5.5 billion liters (1.4 billion gallons) become used oil. Of this total, approximately 3.1 billion liters (800 million gallons) are handled through the used oil management system. About 90 percent of reclaimed oil is burned as fuel.

Used motor oil has been used in highway construction by 2 state highway agencies. Two states have used motor oil in the friction course of the asphalt concrete pavement. One state have investigated its use in the structural course.

The survey illustrated that the 2 reporting states consider used motor oil as less costly. Considering the engineering performance, the 2 state highway agencies evaluated used motor oil of equal performance.

Waste Paper

Around 65 million metric tons (72 million tons) of paper and paperboard are discarded annually. During 1989, about 16.5 million metric tons (18 million tons) of waste paper were recycled.

According to the questionnaire responses, only one state is now performing research on the use of waste paper in pavement base. This state indicated that using waste paper in highway construction is of equal cost, and has a comparable performance.

Combustion Ash

In 1990, the amount of municipal solid waste that was burned in the United States reached 29 million metric tons (32 million tons), creating approximately 7.3 million metric tons (8.0 million tons) of combustion ash. The survey indicated that one highway agency is using combustion ash in highway construction. That state reported its experience in using combustion ash as an aggregate in the subgrade course.

The economical evaluation of combustion ash showed that it is a less economical material compared to raw materials, but a better solution when compared to conventional materials.

Performing additional analysis is important to illustrate the significance of involving waste materials in highway construction. This analysis is conducted in the next part of this chapter.

Analysis of Data Obtained by Questionnaire

A survey questionnaire was sent to all state highway agencies within the United States. Thirty five responses were received. The purpose of the survey was to obtain information concerning the various states' practice in recycling. Information was obtained concerning the type of waste materials, by-products and pavement course types they are using and their evaluations of the use of these additives in terms of economic and engineering performance.

The result of using different types of waste materials and their pavement courses is illustrated in table 4.1 and summarized in Figure 4.1. Figure 4.2 presents the percentage of highway agencies using waste materials in different pavement courses. Table 4.2 shows the result of the survey of state highway agencies (SHA) for the economical evaluation. Table 4.3 shows the SHA summary for engineering performance.

Table 4.1 Number of uses of waste materials and corresponding pavement courses.

Waste Material	*States Responded*	Asphaltic Conc Pav.		Portl. Cem. Pavement	Pavement Base
		Friction course	Structural course		
Reclaimed Asphalt Concrete	*35*	11	32	1	23
Fly Ash	*31*	3	3	28	9
Scrap Tires	*18*	7	9	-	-
Blast Furnace Slag	*15*	7	7	9	8
Waste Glass	*10*	1	4	-	5
Steel Slag	*9*	7	1	1	2
Bottom Ash	*7*	2	1	1	4
Mining Waste	*7*	4	4	2	2
Building Rubble	*6*	-	-	-	3
Roof Shingles	*6*	3	5	-	-
Plastics	*3*	-	3	-	-
Rec P C	*3*	-	2	3	2
Used Motor Oil	*2*	2	1	-	-
Combustion Ash	*1*	-	-	-	-
Waste Paper	*1*	-	-	-	1
Others	*1*	-	-	-	-

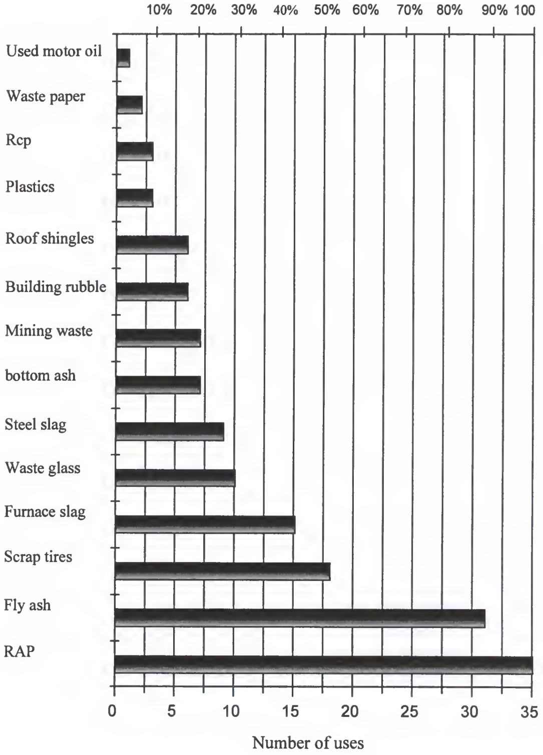

Figure 4.1 Number of uses for waste materials by states

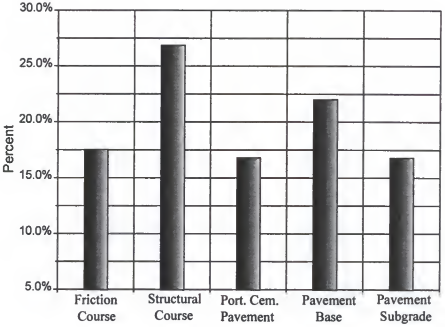

Figure 4.2 Percentages of highway agencies using waste material in different pavement courses.

Table 4.2 Economical evaluation for waste materials.

Waste Material	*States Responded*	More cost	Equal cost	Less cost
Reclaimed Asphalt Concrete	*35*	-	6	28
Fly Ash	*31*	2	9	20
Scrap Tires	*18*	17	-	-
Blast Furnace Slag	*15*	1	11	3
Waste Glass	*10*	4	4	2
Steel Slag	*9*	3	4	2
Bottom Ash	*7*	2	3	1
Mining Waste	*7*	1	3	3
Building Rubble	*6*	-	1	5
Roof Shingles	*6*	-	2	4
Plastics	*3*	2	-	1
Rec P C	*3*	-	1	2
Used Motor Oil	*2*	-	-	2
Combustion Ash	*1*	-	-	1
Waste Paper	*1*	-	1	-
Others	*1*	1	-	-

Table 4.3 Engineering Performance evaluation for waste materials.

Waste Material	*States Responded*	Better	Equal	worse
Reclaimed Asphalt Concrete	*35*	1	32	1
Fly Ash	*31*	10	19	2
Scrap Tires	*18*	2	8	7
Blast Furnace Slag	*15*	4	9	1
Waste Glass	*10*	-	10	-
Steel Slag	*9*	5	2	2
Bottom Ash	*7*	-	5	1
Mining Waste	*7*	2	4	1
Building Rubble	*6*	-	5	1
Roof Shingles	*6*	-	6	-
Plastics	*3*	1	1	-
Rec P C	*3*	-	3	-
Used Motor Oil	*2*	-	2	-
Combustion Ash	*1*	-	-	1
Waste Paper	*1*	-	-	1
Others	*1*	-	-	1

The following section illustrates a ranking method for waste materials and by-products according to number of uses, economic evaluation, and technical performance.

Ranking of Used Wastes and By-Products

The ranking of wastes and by-products is of greatest interest for reuse and recycling in transportation construction. This ranking is conducted based on the results of the survey of highway agencies (SHA). The overall economic and technical feasibility of these wastes, when competing with conventional materials, were based on number of uses, cost evaluations and savings through dumping charges and/or reduced landfill fees, transportation costs, and engineering performance.

The ranking was performed by assigning certain values for different categorical evaluations. In the category which evaluates cost, the value of 1 is assigned to waste materials that is more costly to use. A value of 2 is assigned to waste material that equals the cost of using conventional materials, and a value of 3 means the waste material costs less to use than conventional materials. In judging technical performance, the highest value of 3 is given to the better performance, 2 is given to the equal performance, and the number 1 is given when the performance of the additive is less than that of the conventional material.

To find the rank of the wastes and by-products, the total score for each waste material is calculated based on the highway agencies evaluations. Each cell contains the number of the states votes in each different categorical evaluation. Each number is multiplied by its assigned score, i.e., by 1 for less cost, 2 for equal and 3 for more cost. Each cell enclosing the number of states voting in the engineering performance category is multiplied by the assigned number; i.e., 3 for better, 2 for equal, and 1 for poor performance. All these figures are added together on a row basis, for each specific waste material, then added to the number of states that responded about that specific material. Then, the total score for each row of the matrix is calculated and these total scores are ranked from highest to lowest. The waste material that accumulated the highest total score is ranked number one, and so on, with lowest total score assigned the rank number 16. The ranking for wastes extracted from the SHA is summarized in table 4.4. Reclaimed asphalt concrete and the fly ash earned the ranks one and two, but there is a little difference between their total scores. A significant drop in total score occurs for the blast furnace slag which is ranked in the third position.

Table 4.4 Ranking of wastes and by-products according to highway agencies survey.

		Economic			*Engineering*				
Waste Material	*No. of States*	More cost	Equal cost	Less cost	Better	Equal	worse	Total Score	**Rank**
Reclaimed Asphalt Con.	*35*		12	84	3	64	1	199	**1**
Fly Ash	*31*	2	18	60	30	38	2	181	**2**
Blast Furnace Slag	*15*	1	22	9	12	18	1	78	**3**
Scrap Tires	*18*	17			6	16	7	64	**4**
Waste Glass	*10*	4	8	6		20		48	**5**
Steel Slag	*9*	3	8	6	15	4	2	47	**6**
Mining Waste	*7*	1	6	9	6	8	1	38	**7**
Building Rubble	*6*		2	15		10	1	34	**8**
Roof Shingles	*6*		4	12		12		34	**9**
Bottom Ash	*7*	2	6	3		10	1	29	**10**
Rec P C	*3*		2	6		6		17	**11**
Plastics	*3*	2		3	3	2		13	**12**
Used Motor Oil	*2*			6		4		12	**13**
Combustion Ash	*1*			3			1	5	**14**
Waste Paper	*1*		2				1	4	**15**
Others	*1*	1					1	3	**16**

The next phase of this chapter conducts statistical analysis to illustrate the relevance and evaluates the economic and engineering performance of these materials.

Statistical Analysis of SHA results

The two-way contingency tables method was used to evaluate the results of the SHA. One of the applications of the contingency tables is the study of the relationship that may exist between two variables. This study uses this sets of contingency tables. The tables are organized according to two variables: the cost evaluation and engineering performance of each type of waste material. This analysis emphasizes the relationship between the type of waste materials and both their cost and performance.

For example, these two variables, type and cost in one case, and type and performance in another case, are classified in r rows and c columns, respectively. Let n_{ij} be the number of observation in (ij) cell, and let $n_{i.}$, $n_{.j}$, and $n_{..}$ represent the totals of the i^{th} row, j^{th} column, and the grand total, respectively.

	b_1	b_2	......	b_c	*Total*
a_1	n_{11}	n_{12}	......	n_{1c}	$n_{1.}$
a_2	n_{21}		......		.
.					.
a_r	n_{r1}		......		$n_{r.}$
Total	$n_{.1}$	$n_{.2}$	......	$n_{.c}$	$n_{..}$

We wish to test the two hypothesis H_0, and H_1, where H_0 and H_1 are denoted as the null and the alternative hypothesis, respectively.

H_0: The two variables of classification, a and b are independent.

H_1: There is a significant association between the two variables.

Now we define the *T* statistic test, where

$$T = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{\left(n_{ij} - \frac{n_{i.} x\ n_{.j}}{n_{..}}\right)^2}{\frac{n_{i.} x\ n_{.j}}{n_{..}}}$$

the T statistic has approximately the χ^2 distribution with *(r-1)(c-1)* degrees of freedom. The null hypothesis is rejected when the *T* value is larger, i.e., if *T* greater than $\chi^2_{\alpha,(r-1)(c-1)}$.

The statistical analysis for finding relationship between the waste material type and the cost and engineering performance was accomplished with the aid of the SAS PROC FREQ procedure which performs advanced analysis for contingency tables.

The first test is finding the association between the waste material type and the cost.

Two types of hypothesis could be tested

H_0: the type of waste material and cost are independent

H_1: there is a dependency between type of waste and cost.

A partial output is shown as follows:

```
          STATISTICS FOR TABLE OF TYPE BY COST

Statistic                       DF    Value        Prob
  ÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆ
  Chi-Square                    30   124.883       0.001
  Likelihood Ratio Chi-Square   30   125.476       0.001
  Mantel-Haenszel Chi-Square     1    16.136       0.001
  Phi Coefficient                      0.906
  Contingency Coefficient              0.672
  Cramer's V                           0.641
```

The value of T is calculated by SAS, and it is given as *Chi-Square Value* with 30 degrees of freedom in the previous output. The T value of the type-cost test has a value of 124.883 which is greater than the tabulated value of the χ^2

with a 30 degrees of freedom at $\alpha=0.05$, $\chi^2_{0.05,30} = 43.77$. The null hypothesis is then rejected. The conclusion shows significant dependency between the waste type and the cost evaluation at the 5% level.

The second test is checking the dependency between the waste material type and the engineering performance. The two hypotheses of concern are

H_0: the type of waste material and engineering performance are independent

H_1: there is a dependency between type of waste and engineering performance.

A partial output is shown as follows

```
      STATISTICS FOR TABLE OF TYPE BY PERFORM

Statistic                     DF     Value        Prob
ÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆÆ
Chi-Square                    30    75.112       0.001
Likelihood Ratio Chi-Square   30    70.357       0.001
Mantel-Haenszel Chi-Square     1     2.668       0.102
Phi Coefficient                      0.708
Contingency Coefficient              0.578
Cramer's V                           0.500
```

As in the previous test, the value of *T*, which is given as *Chi-Square Value* with 30 degrees of freedom, has a value of

75.11 which is greater than the tabulated value of the χ^2 with a 30 degrees of freedom at $\alpha=0.05$, $\chi^2_{0.05,30} = 43.77$. Then the null hypothesis is rejected. We conclude that significant dependency exists between the waste type and its engineering performance at the 5% level. Complete input and output files for the two tests are listed in appendix B.

Highway Construction Rates of Consumption

Highway construction, one of the major consumers of raw materials, produces huge quantities of wastes. The consumption of these raw materials should be optimized and modeled.

The consumed materials quantities involving limestone are obtained from Florida Department of Transportation's construction contract history. Chapter 3 describes this data which will be used in statistical analysis as well as model development in this research.

Asphalt Concrete Pavement

The asphalt concrete pavement which is known also as the flexible pavement is built up several layers and consists of friction, structural, base and subbase courses. The highway construction industry consumes a tremendous amount of asphalt concrete every year. Different materials are used for asphalt concrete pavement, such as limestone, crushed rock, and gravel. These aggregates are attached together using a bituminous cement, usually asphaltic, which is the basis of flexible pavement.

The record of the quantities of asphalt concrete pavement used within the state of Florida were obtained from the FDOT's contract history for the last 10 years through 5603 different paving jobs. This data was analyzed to calculate the used limestone quantities for these specific years. Figure 4.3 illustrates the trend of asphalt concrete pavement quantities for the years 1986 to 1995. The used quantities vary on a yearly bases depending on the highway construction activities; i.e., building new roads, maintenance for old roads, interstate and turnpike activities.

The statistical analysis to illustrate maximum, minimum, mean, and standard divination were compiled with the aid of the SAS PROC MEANS. The output result is shown as follows:

Variable	N. Obs.	Mean	Std Dev	Minimum	Maximum
ASPHL	10	3707828.90	822241.25	2525090.0	4927311.0

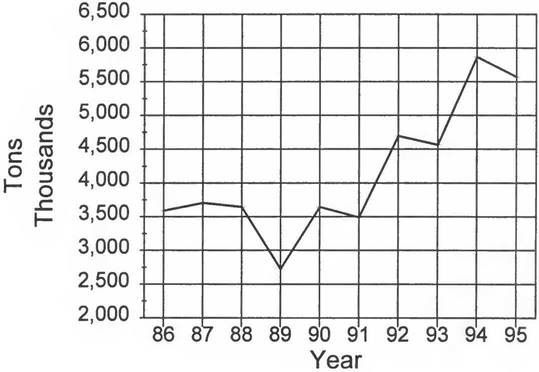

Figure 4.3 Quantities of asphalt concrete pavement.

Portland Cement Concrete Pavement

Portland cement concrete pavement is also known as rigid pavement. Thickness of rigid highway pavements range between 15 to 25 centimeters (6 to 10 inches). The quantities of concrete were collected from 123 different jobs within Florida (as discussed in chapter 3). These quantities were converted from cubic yards to tons to include the limestone quantities that were involved in portland cement concrete. Limestone acted as course aggregate in concrete and in the production of portland cement.

The following table contains the results of the statistical analysis that define the maximum, minimum, mean, and standard divination of the quantities of portland cement concrete pavement.

Variable	N. Obs.	Mean	Std Dev	Minimum	Maximum
POR_PAV	10	86367.90	90379.53	14867.00	325606.00

The quantities of portland cement concrete pavement, recorded in Figure 4.4, indicate that the portland cement concrete pavement is less frequently used than asphalt concrete pavement in highway construction and maintenance in Florida.

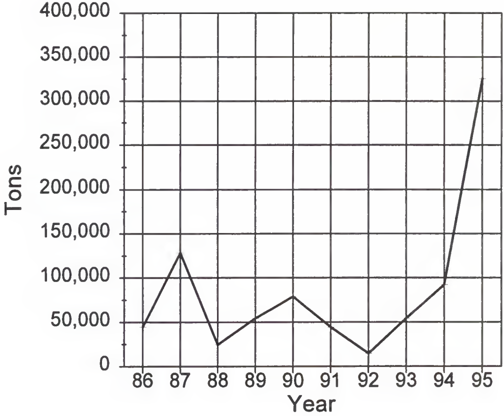

Figure 4.4 Quantities for portland cement concrete pavement.

Portland Cement Concrete

Portland cement concrete is used in a widely in highway construction. Portland cement concrete is used in substructures, end walls, bulkheads, culverts, and the manufacturing of concrete pipelines. All these quantities are added together to calculate the amount of portland cement concrete used in a 10 year period. Then, the data of limestone quantities was obtained. In order to calculate the amount of concrete used in pipelines, the measurements of the lengths of the pipelines are multiplied by the circumference and pipe thickness to figure the volume of concrete. Data for portland cement concrete were obtained from 4596 different jobs, and the pipelines data were collected through 6540 different job within Florida. The concrete quantities are shown in figures 4.5 and 4.6.

According to the SAS PROC MEANS analysis, the quantities of pipeline concrete are shown below:

Variable	N. OBS	Mean	Std Dev	Minimum	Maximum
CONC_PI	10	13367.00	5548.17	6836.00	22151.00

Similarly, the results of the statistical analysis of portland cement concrete quantities used during the years 1986 to 1995 are shown in the following table:

Variable	N. OBS	Mean	Std Dev	Minimum	Maximum
CONC	10	434876.50	199884.08	56154.00	690589.00

Figure 4.7 charts the total consumption of limestone during the years 1986 to 1995.

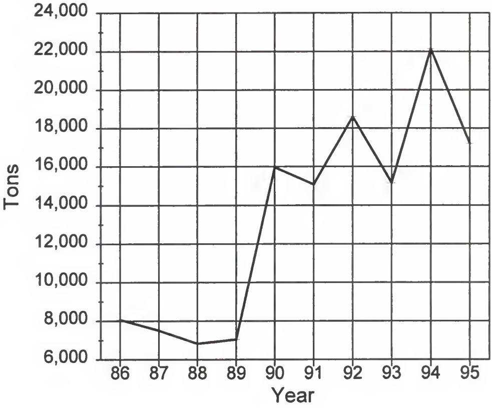

Figure 4.5 Concrete quantities in pipelines.

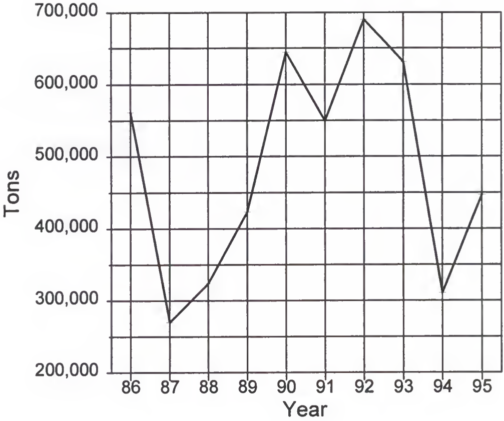

Figure 4.6 Portland cement concrete quantities.

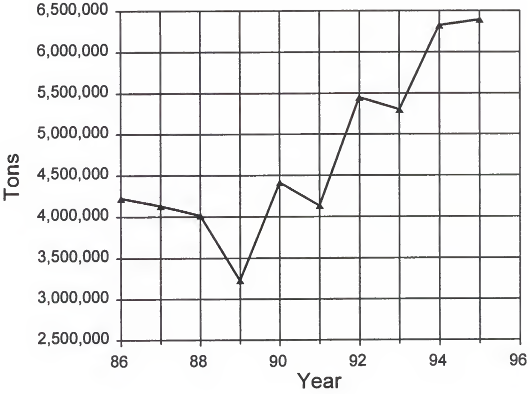

Figure 4.7 Total limestone quantities used in highway construction in Florida.

CHAPTER 5
SYSTEMS ANALYSIS AND MODELING

Introduction

Systems analysis is a broad research strategy that involves the use of mathematical techniques and concepts, but is a systematic and scientific approach to the solution of complex problems. It provides a framework of thought designed to help decision makers to choose a course of action, or to predict the outcome of one or more courses of desirable action. In addition, it is the logical and orderly organization of data and information into models, followed by testing and exploration.

Any system is composed of three elements: input, output, and a transition operator linking the two. A system is said to be continuous if input and the output are measured as continuous variables. In contrast, a discrete system is one in which the input and output can be measured only at distinct points. Figure 5.1 illustrates the continuous and discrete variables. System analysis may be identified in seven stages in application (Nickerson, 1978).

These stages and their connections are provided in Figure 5.2, and are discussed in this chapter.

Problem recognition

The recognition that a problem (or a group of a connected problems) exist and is sufficiently to investigate in detail is an important step. The recognition that research is necessary is as important as the choice of method to use in the research.

Definition and Boundaries of the Problem

Once a problem has been recognized, an analytical solution requires simplifying it. The difficult judgement of the relative importance of elements of the problem for inclusion or exclusion, and the balancing of their relevance to the analysis, will frequently depend on experience in systems analysis (Casley & Kumar, 1984). This is one stage at which the experienced systems analyst can make his most valuable contribution. The delicate balance between simplification and complexity, while retaining sufficient relationship to the original problem so the analytical solution will be recognizably appropriate, will almost certainly determine the success or failure of the investigation.

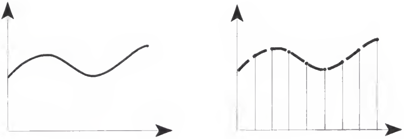

Figure 5.1. (a) a continuous variable, (b) a discrete variable

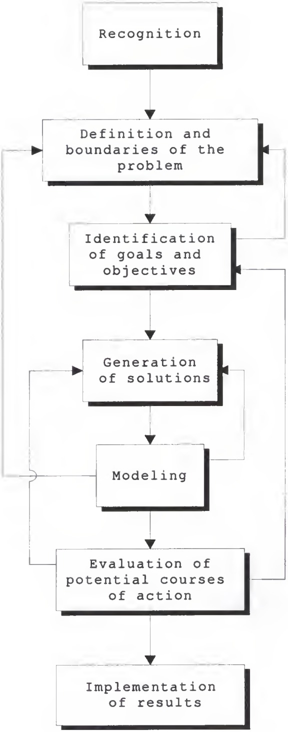
Recognition
Definition and boundaries of the problem
Identification of goals and objectives
Generation of solutions
Modeling
Evaluation of potential courses of action
Implementation of results

Figure 5.2 Phases of systems analysis.

Identification of the Hierarchy of Goals and Objectives

Once the problem has been defined, it should be possible to define the goals and objectives of the investigation. Usually, these goals and objectives will form a hierarchy, with the major objectives progressively sub-divided to a series of minor objectives. In such a hierarchy, one must determine priorities for the various stages relative to the amount of effort required to meet the objectives.

Generation of Solutions

At this point, it will usually be possible for the investigator to generate possible solutions to the problem. In general, a systems analyst seeks an analytical solution of the greatest possible generality because he or she can use previous work on similar problems and the mathematics of their solution. It is rarely that any specific problem has only one possible solution. Again, the experience of the analyst will be helpful in choosing the most appropriate family from which to derive his analytical solution (Devore & Peck, 1986). Frequently, the analyst will deliberately develop several solutions before deciding on the one which is most appropriate to his problem.

Modeling

When the appropriate alternatives have been examined, the important phase of modeling the complex, dynamic interrelationships between various aspects of the problem can begin. Such modeling must be done with a full awareness of the inherent uncertainties in the various processes to be modeled, and of the feed-back mechanisms which may considerably complicate both the understanding and the tractability of the system. Similarly, the modeling must itself bear in mind the complex series of rules which will necessarily be used in reaching a decision about appropriate courses of action (Jefferson, 1994).

Evaluation of potential courses of action

Once the modeling is sufficiently advanced to use, at least in a preliminary way, evaluating potential courses of action from the model can begin. In the course of this evaluation, we must investigate the sensitivity of the results of the assumptions made by the model. Discovery of an important flaw in a major assumption may lead to a return to the modeling phase, but, frequently, further progress can be made by relatively simple modifications to the original model.

Implementation of the results

The final phase of systems analysis is the implementation of the results. If the analysis has been carried through in the way described above, the steps to implement the results will usually be fairly obvious. Nevertheless, systems analysis is not complete unless the analysis is implemented; in this respect many past systems analyses have been incomplete.

The order in which the phases are undertaken may be varied, or it may be necessary to iterate through them in various patterns.

Modeling Definition

The definition of the word "model" has three different versions: a noun, an adjective, and a verb. As a noun, it is a representation, in the sense in which an architect constructs a small-scale model of a building or a scientist a large-scale model of an atom. As an adjective, "model" implies a degree of perfection or idealization, as in a model home, or a model person. As a verb, "to model" means to simulate, to reveal, to show what a thing is like (Martens & Don, 1969).

We can extend the application of models if we construct models using symbols instead of things. For example, models of national economies have been built using water to represent the flows of wealth. Mathematical symbols are easier to use to represent components of the economy, and mathematical equations are more flexible in representing their interrelationships.

the model usually contains a dependent variable of interest, explained in term of independent variables. In the case of rates of consumption construction, we want to simulate the past and current consumption rates in terms of various influencing factors. In addition, we wish to predict future consumption rates. Modeling technique is one of the systems analysis' stage.

In the previous chapters, we included a discussion of data collection, and data management considerations. In this chapter, several general modeling concepts should be illustrated prior to undertaking the formal statistical procedures.

Stages in Statistical Modeling

There are five stages in the process of statistical modeling. These stages are:

Identification

This is a process of finding or choosing an appropriate model for a given situation.

Estimating and Fitting

To use a model in practice, we must put it into a detailed numerical form. This is the stage of moving from the general model form to a specific numerical form, called model fitting. The process of assigning numerical values of parameter is called estimation.

Validation

Validation takes place in three stages: the development stage of the model, when a fitted model reveals further aspects of the data; testing new data; and applying monitor procedures to check whether an initially satisfactory model remains valid in use.

Application

The application of statistical models is within fields like engineering, physics, psychology, or economics. The modeling process cannot be separated from the ultimate purpose of which the model. We therefore need to look at interactions between model identification, fitting, and validation, and the intended application of the model.

Iteration

The modeling procedure involves going back a stage or two to use additional information, as shown in Figure 5.3. The analysis should clearly state the objective of the model at the start of the process. Each iteration of the modeling procedure should push the model closer to its objective.

Mechanistic Model

Variables can be treated as deterministic and arise in a number of ways. For example, a sales model may contain the variable *n*, the number of sales outlets. This value is precisely known and controllable. Another example, a recreational facility, might assess a yearly membership fee of $100, and then charge $2 per visit. Then with x as the number of visits in a year and y as the member's annual cost, the value y is determined by the equation

$$y = 100 + x$$

The value y is known once the value x is known. In another example, one of the simplest models of growth of a population of organisms is given by the differential equation:

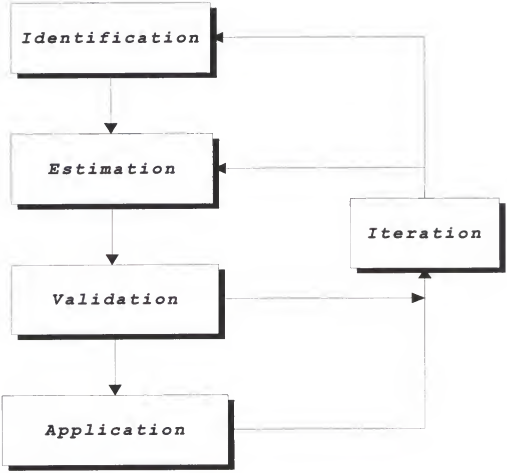

Figure 5.3 Illustration for the stages of modeling.

$$\frac{dy}{dt} = ry$$

where y is the density of the population at time t, and r is a constant. We can use the properties of the particular kind of symbolic logic represented by differential equations to show that the density of the population at any point in time may also be represented by the equation

$$y = y_o e^{at}$$

where, again, y is the density of the population at time t, y_o is the density at time $t=0$, a is a constant, and e *is* the base of the natural logarithms.

Probabilistic Model

In a mechanistic, or deterministic modeling case, it is possible to write $x = 3$ and be totally clear as to what this statement means. With random variables, this is not the case. For example, let x represent a child's age and y represent the vocabulary size. Then it is clear that an increase in the value x is associated with an increase in the value of y. However, many factors other than age affect the vocabulary size. Some of these factors are: parents' educational level, home environment, and amount of schooling.

We may formulate the model shown in the mechanistic case in a very different way, exploiting the variability of living organisms as a basic property of the model. Probabilistic models in practice consist of both a deterministic and a probabilistic component (Hoel & Jessen, 1971).

Such models employ a quite different branch of mathematics: differential equations and calculus. A simple example, corresponding to the mechanistic model of the exponential growth, is:

$$\frac{dy}{dt} = [a + y(t)]\, y$$

where y is the density of population at time t, a is a constant, and $y(t)$ is a random variable with mean zero. This means that the value of $y(t)$ is different from occasion to occasion, being taken from a random distribution with no correlation between the fluctuations at successive instants.

CHAPTER 6
MODELING AND FORECASTING PROCEDURES

Introduction

The world scene is characterized by increasing uncertainty about the future. Evidence suggests that our social and economic systems are becoming more unstable, and that, for example, the rapid rises in raw material prices, increasing pollution and exponential population growth are symptoms of that instability (Anderson, 1983). In parallel with this increasing uncertainty, the consequences of bad decisions are becoming more costly in human, environmental and financial terms. As a result of these tendencies, and of growing social pressures for better planning, the importance of forecasting as a management activity is likely to increase.

Forecasting and Time Series

Forecasting is defined as the predictions of future events and conditions. Forecasting is important in many types of organizations since predictions of future events must be incorporated into the decision-making process. The government of a country must be able to forecast such things as air quality, water quality, unemployment rate, inflation rate, and welfare payments in order to formulate its policies. In marketing, reliable forecasts of market demand must be available so that sales strategies can be planned. For example, the demand for products must be forecasted in order to plan total promotional efforts, demand in various market regions and among various consumer groups must be predicted in order to plan effective advertising strategies. Forecasts of demand for individual products can be translated into forecasts of raw material requirements so that minimizing and finding alternatives for this material can be planned.

In generating a forecast of events that will occur in the future, a forecaster must rely on information concerning events that have occurred in the past. That is, in order to prepare a forecast, a forecaster must analyze past data and must base the forecast on the results of this analysis (Anderson, 1983).

Choosing a Forecasting Technique

Quantitative forecasting methods are used when historical data are available: Time series models predict future values of the variable of interest solely on the basis of the historical pattern of that variable, assuming that the historical pattern will continue. Causal models predict future values of the variable of interest based on the relationship between that variable and other variables. Qualitative forecasting techniques are used when historical data are scarce or not available at all and depend on the opinions of experts who subjectively predict future events. It should also be noted that in actual practice forecasting systems must employ both quantitative and qualitative methods. Forecasts generated by quantitative methods are almost always subjectively evaluated by management. This evaluation may result in a modification of the forecast based on the manager's "expert opinion."

The types of forecasting procedures can be classified into three broad categories (Chatfield, 1984):

Subjective Forecasting

In this method, forecasts can be made on a subjective basis using intuition judgement, and expert opinion as mentioned above.

Univariate Forecasting

In this method, the forecasts completely depend on past observation of one variable in a given time span. For example, the prediction of future sales of a product would be based entirely on past sales.

Multivariate Forecasting

The effecting factor means to take observations of other variables into account. Multi-regression models, like the prediction of future sales of a certain product based on population, rely on this kind of forecasting.

In choosing a forecasting technique, the forecaster must consider the following factors (Bowerman & O'connell, 1979):

- The forecast form desired
- The time frame
- The pattern of data
- The cost of forecasting
- The accuracy desired
- The availability of data, and
- The ease of operation and understanding.

Available data quality and quantity could affect the modeling and forecasting accuracy by causing errors. Errors and uncertainty in forecasting are described next.

Uncertainty and Errors in Forecasting

Unfortunately, all forecasting situations involve some degree of uncertainty. Forecasters recognize this fact by including an irregular component in the description of a time series. The presence of this irregular component, which represents unexplained or unpredictable fluctuation in the data, means that some error in forecasting must be anticipated. If the effect of the irregular component is substantial, our ability to forecast accurately will be limited. If, however, the effect of the irregular components is small, determination of the appropriate trend should allow us to forecast with more accuracy.

Another source of uncertainty is the availability of data. We shall always find that to obtain an accurate fit requires more data than we can either practically or financially obtain. We can have accurate data on some variables, data on other variables will be inadequate. We need always to bear in mind that our model is always a model, it is not the reality.

We now consider the problem of measuring forecasting errors. Denote the actual value of the variable of interest in time period t as Y_t. Then if we denote the predicted value of Y_t by $\hat{Y}_t$, we can subtract the predicted value of $\hat{Y}_t$ from the actual value Y_t to obtain the forecast error e_t, which defined as

$$e_t = Y_t - \hat{Y}_t$$

If the forecasting of errors over time indicates that the forecasting method is appropriate, it is important to measure the magnitude of the errors to determine whether accurate forecasting is possible. In order to do this, one should consider the sum of all forecast errors over time, which is defined by the following equation:

$$\sum_{t=1}^{n} (Y_t - \hat{Y}_t)$$

This equation calculates the summation of the differences between the predicted $\hat{Y}_t$ and the actual Y_t values from time period $t=1$ through time period $t=n$, where n is the total number of the observed periods.

The General Linear Model

The simplest and quickest method for determining a straight line is to choose that line which can best be drawn by eye. Although such a method creates a reasonably good image, this procedure is much too subjective and indefinite for purposes of statistical analysis. The general linear model involves polynomials, which includes the straight line and parabolic curve modeling.

Straight Line Regression and the Least Square Method

The least-square method determines the best fitting straight line as that line which minimizes the sum of squares of the length of the vertical-line segments drawn from the observed data points on the scatter diagram to the fitted line (as shown in Figure 6.1). Clearly, the smaller the deviations of the observed value from this line, the closer the best-fitting line will be to the data (Ott, 1985).

Using the mathematical notation, the fitted regression line is described as follows:

$$Y = \beta_o + \beta_1 X + \varepsilon$$

where Y is defined as the dependent variable, the X represents the independent variable, and β_o and β_1 are the parameter estimates of the independent variable and defined as the intercept and the slop, respectively. The random error associated with the model is represented by ε. Rewriting the above equation, the estimated response of $\hat{Y}_i$ at the associated value of X_i could be as follows

$$\hat{Y}_i = \beta_o + \beta_1 X_i$$

Where $\hat{Y}_i$ is the estimated, or the predicted value of the

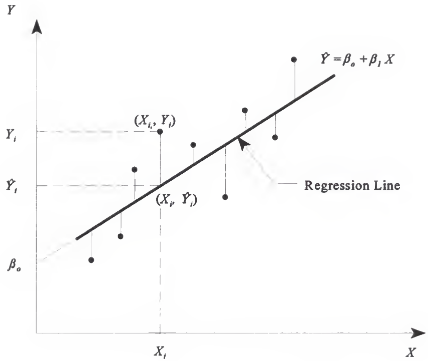

Figure 6.1 Example of the a line model equation

variable of interest in time period t which corresponds to the independent variable X_i, and β_o and β_1 are estimated as the intercept and slop of the fitted line, respectively. The vertical distance between the observed point (X_i , Y_i) and the corresponding point $(X_i , \hat{Y}_i)$ on the fitted line is given by the absolute value $|Y_i - \hat{Y}_i|$. The sum squares of all such distances is then given by

$$\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n}(Y_i - \beta_o - \beta_1 X_i)^2$$

The minimum sum of squares corresponding to the least-squares estimates β_o and β_1 is called the sum of squares of errors, or (SSE)(Bennett, 1979). The measure SSE is of great importance in assigning the quality of the straight-line fit. The SSE is defined by the formula:

$$SSE = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$$

Clearly if SSE equals to zero, the straight line fits perfectly, and every observed point lies on the fitted line. On the contrary, as the fit gets worse, SSE gets larger, since the deviation of points from the regression line will be larger.

Let $\bar{Y}$ denote the sample mean of the observation on Y and $\bar{x}$ denote the sample mean of the value of X. Then the best fitting straight line is determined by the following formula:

$$\beta_o = \bar{Y} - \beta_1 \bar{x}$$

and the slope which is defined as:

$$\beta_1 = \frac{\sum_{i=1}^{n} (X_i - \bar{x})(Y_i - \bar{Y})}{\sum_{i=1}^{n} (X_i - \bar{x})^2}$$

Confidence and Prediction Intervals

Since the regression line is used to model given data, it might be useful if the accuracy of the fitting could be determined. The estimate value of the dependent variable is defined as follows:

$$\hat{Y}_i = \beta_o + \beta_1 X_i$$

Since each possible sample of the n values of the dependent variable gives values of β_o and β_1 that are different from the values given by other samples, each possible sample gives a value of $\hat{Y}_i$ that is different from the values given by other samples. The population of all possible values of $\hat{Y}_i$ is normally distributed with variance (Kleinbaun & Kupper, 1978)

$$\sigma^2 = s^2 \left[\frac{1}{n} + \frac{(X_o - \bar{x})^2}{\sum_{i=1}^{n} (X_i - \bar{x}^2)}\right]$$

Where s^2 = sample variance = $\frac{SSE}{n-k}$

K = number of parameters (β_o, and β_1)

n = number of samples

$\bar{x}$ = mean value of x = $\sum_{i=1}^{n} \frac{x_i}{n}$

therefore, the confidence interval for the estimate value of the mean value of $\hat{Y}$ is expressed as follows:

$$\hat{Y}_i \pm t_{(n-k),\alpha/2} . S \sqrt{\frac{1}{n} + \frac{(X_o - \bar{x})^2}{\sum_{i=1}^{n} (X_i - \bar{x})^2}}$$

where $t_{(n-k),\alpha/2}$ = t test statistics at $\alpha/2$

(n-k) = degrees of freedom

$\alpha/2$ = selected confidence interval probability.

This interval establishes the confidence of predictions for the mean value of $\hat{Y}$. The objective is to find for a given

$X=X_o$ a confidence interval for the mean value of $\hat{Y}$ at X_o. For example, if α of 0.05 is selected, the expected actual mean value of $\hat{Y}$ exist within the interval of 95%.

The estimated point prediction of an individual value of the dependent Value Y_o is defined as follows:

$$\hat{Y}_o \pm t_{(n-k),\alpha/2} \cdot s \sqrt{1+\frac{1}{n}+\frac{(X_o-\bar{x})^2}{\sum_{i=1}^{n}(X_i-\bar{x})^2}}$$

It should be noted that the confidence interval for the prediction of a particular value of Y is larger than that of the mean value of Y since the real number 1 is added under the square root. Figure 6.2 illustrates the confidence interval.

Multiple Regression Models

In the multiple regression models, the number of basic independent variables may be greater than one. The general form of the regression model for k independent variables is given by

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_k X_k + \varepsilon$$

where β_o, β_1, β_2,...., β_k are the regression coefficients that need to be estimated, and X_1, X_2,...., X_k are the independent variables.

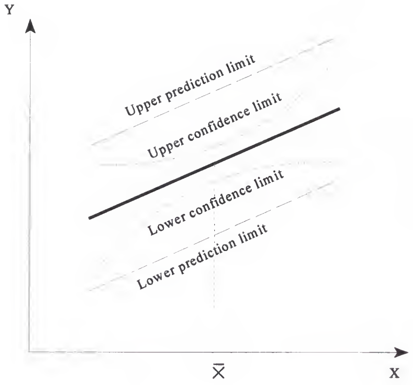

Figure 6.2 Confidence and Predication Intervals for $\hat{Y}$ and Y.

When the number of the independent variables is two or more, the graphical representation of the model becomes harder. The regression equation will no longer exist in a two-dimensional space but will be a surface in *k+1* dimensional space, where *k* is the number of independent variables (bowerman & O'connell, 1993). This model of a multi-dimension space is difficult to represent. In a special case $k=2$, the problem is to find the surface in three-dimensional space that best fits the scatter of X_{1i}, X_{2i}, and Y_i as shown in Figure 6.3.

Quadratic Models

The quadratic regression model is a special case of the general linear model. Using the previous equation for the multiple regression, the parabolic model is identified when k=2 as shown in the following equation

$$Y = \beta_o + \beta_1 X + \beta_2 X^2 + \varepsilon$$

Assuming that the parabolic model, as given by the previous equation, is appropriate for describing the relationship between X and Y, we must then determine a specifically estimated parabola which best fit the data.

As in a straight-line case, this best fitting parabola may be determined by extending the least-squares method to find the best fit for the data. The least-squares estimates of the parabolic model are chosen so as to minimize the sum of squares of deviations of observed points from corresponding points on the fitted parabola (SSE) as shown in Figure 6.3. Letting β_o, β_1, and β_2 denote the least-squares estimates of the unknown regression coefficients of the parabolic model and letting $\hat{Y}_i$ denote the value of the predicted response at X_i, the estimated parabola is written as follows:

$$\hat{Y}_i = \beta_o + \beta_1 X_i + \beta_2 X_i^2$$

The minimum sum of squares obtained using this least-square parabola is

$$SSE = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n} (Y_i - \beta_o - \beta_1 X_i - \beta_2 X_i^2)^2$$

The precise formulas for the parameters β_o, β_1, and β_2 are quite complex and become even more so for polynomials of orders higher than two. Therefore, computer software such as the SAS packages were used to obtain these parameters.

Variables Selection

Multiple regression models are powerful tools for modeling and forecasting, but there are several problems with the method that needs to be considered. First, the

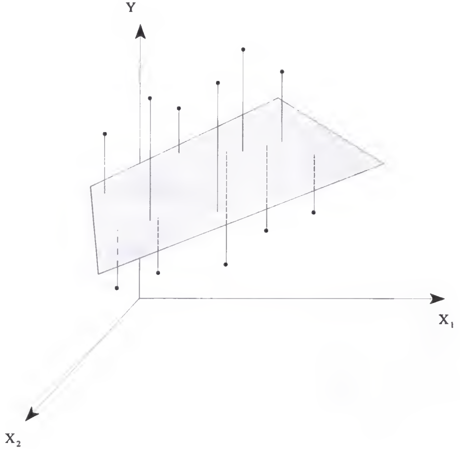

Figure 6.3. Best fitting plane for three-dimensional data.

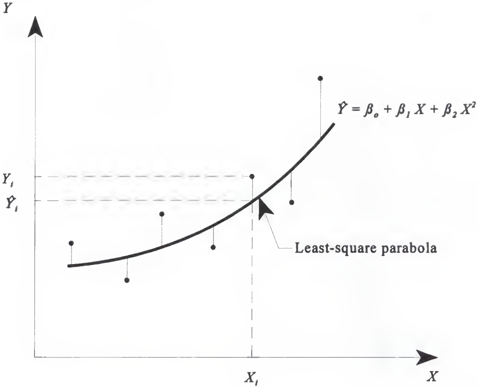

Figure 6.4. Example of a parabolic model equation.

availability of computer programs has resulted in a tendency to put too many explanatory variables into the model with improbable results. It is suggested to check the coefficient of determination, R^2, to be as heigh as possible, hence eliminating unnecessary independent variables. The R^2 coefficient is defined as the proportion of the total variation in the n observed values of the dependent variable that is explained by the overall regression model (Chatfield, 1984). In mathematical form, R^2 is defined as follows:

$$R^2 = \frac{\textit{Explained variation}}{\textit{Total variation}}$$
$$=1 - \frac{\textit{Unexplained variation}}{\textit{Total variation}}$$

where

Explained variation $= \sum_{i=1}^{n} (\hat{Y}_i - \bar{y})^2$

Unexplained variation $= \sum_{i=1}^{n} (Y_i - \hat{Y}_{1i})^2$

Total variation = Explained variation + Unexamined variation

In regression, the independent variables are usually not independent at all, and if some of them are highly correlated, there may be singularity problems. It is, therefore, advisable to look at the correlation matrix of the independent variables before carrying out a multiple regression, so that, if necessary, some variables can be excluded. It is unnecessary for the explanatory variables to be completely independent, but large correlations should be avoided.

Fundamental Assumptions

The least-square method for producing the general linear model is based on specific fundamental assumptions concerning the population of interest. When the assumptions are true, then the model is a precise method of prediction. These assumptions are as follows:

1. For each specific combination of values of the independent variables X_1, $X_2, \ldots, X_n$, is a random variable with a certain probability distribution.
2. The Y observations are statistically independent of one another.
3. The random error ε is assumed to have a mean equal to zero.
4. The random error ε is assumed to be independent among different observations.
5. The random error ε is assumed to have a normal probability distribution

6. The random error ε is assumed to be constant over all values of the independent variables.

Developing A Mechanistic Model

Modeling is a process approach for describing the behavior of a system. Process falls into three categories: transport or flow, transformation and storage. These categories are organized according to two different categories: extensive or through quantities and intensive or across quantities. Extensive variables are characterized by flow through quantities such as mass, volume, force, and heat flows. Intensive variables are measures of many intensities or potentials across system components. Intensive variables are a driving force for the extensive variables. Examples of intensive variables are: pressure, temperature, voltage, and velocity.

A model is defined as a mathematical representation of a system. Modeling is the process of developing that presentation.

To construct a mathematical model to address the problem of managing the consumption of raw materials, a mathematical framework relating consumption and feedback recycling must be developed in keeping with the principle of mass conservation. *Antoine Lavoisier* was the first to formulate such a law in the eighteenth century in France. The conservation of mass law states: "*The total amount of a matter that undergoes a physical process in a closed system remains constant.*"

The mechanistic model, which is in the form of a time dependent equation, will relate the material sustainability as a function of the rate of consumption, and recycling rate. The simulation will be in the form of a water tank, as shown in Figure 6.5, with a simple flow system. Consider the volume-balance equation for the flow through the water tank is defined as

$$V_o = V - V_r + V_u \tag{1}$$

Where

V_o is the initial volume of water in the reservoir at time t_o

V is the volume of water in reservoir at time t

V_r is the volume of combined recycled and lost water at time t, *and*

V_u is the volume of delivered water.

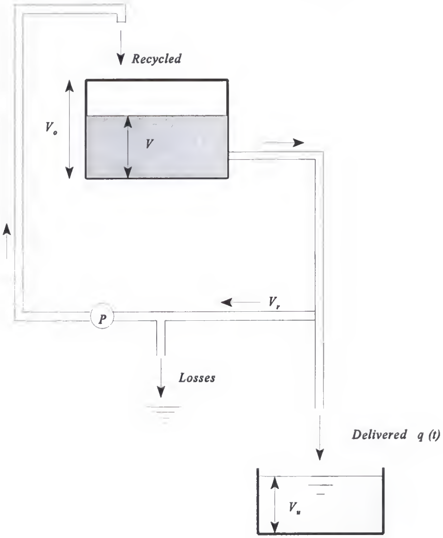

Figure 6.5 An Illustration for that tank that simulate the mechanistic model.

Consider that the water discharge rate is q cubic yards per year (CY/yr). If V_u is the discharged volume, then $g.V_u$ CY is the recycled and lost water, where

$$g = \text{Percent Recycled } - \text{Percent Losses} \tag{2}$$

The rate at which water is discharged from the reservoir is

$$\frac{dV_u}{dt} = q(t) \tag{3}$$

and the rate of loss is

$$\frac{dv_r}{dt} = g \cdot \frac{dv_u}{dt} = g \cdot q(t) \tag{4}$$

differentiating equation (1) with respect to time, and taking into consideration that V_o is constant, we get

$$0 = \frac{dV}{dt} - \frac{dV_r}{dt} + \frac{dV_u}{dt} \tag{5}$$

Substituting equations (2) and (3) into equation (4) yields

$$0 = \frac{dV}{dt} -g \cdot q(t) + q(t) \tag{6}$$

Note that equation (6) can be written as follows:

$$\frac{dV}{dt} = -(1 - g) \cdot q(t) \tag{7}$$

This equation can be solved by separation of variables, i.e.

$$\int_{V_0}^{V} dV = -\int_{0}^{t}(1 - g) \cdot q(t)\, dt \tag{8}$$

Integrating both sides of equation (8) yields

$$V - V_0 = -(1 - g)\int_{0}^{t} q(t)\, dt \tag{9}$$

or

$$V = V_0 - (1 - g) \int_{0}^{t} q(t)\, dt \tag{10}$$

Consider the special case in which *q(t)* is constant over time, then *q(t)=q*. Equation (10) becomes

$$\boxed{V = V_0 - (1 - g) \cdot q \cdot t} \tag{11}$$

Equation (11) represents the mathematical model to express the volume of water in the reservoir at any time. The reservoir example could simulate the consumption of the natural resources in the highway construction program and can analyze the volume of available reserve of the resources at a certain time.

Example of Using the Mechanistic Model

The following example is given to illustrate the function of the mechanistic model to calculate the reserves of a nonrenewable natural resource in a certain time t. The initial quantity V_0 is known, the extracting rate is given, and the recycling rate is defined.

According to Campbell (Campbell, 1986), the feasible limestone reserves in Florida are about 34 billion tons. The Bureau of Mines suggested that the average extraction rate for the years 1984 to 1994 was 74 million tons annually. This average is assumed to be constant with the time of the example demonstration. Assume that 20 percent of the extracted quantities is recovered. The identification of the model terms are as follows:

t_0 = 0 at 1986

V_0 = 34 billion tons at $t=t_0$

q = 74 million tons/year

g = 20%

t = 10 in 1996

V = unknown quantity at 1996

substituting in equation 11

$$V = 34\ E9 - (1.0 - \frac{20}{100})\ .\ 74\ E6\ .\ 10$$

then the predicted volume of the limestone reserve in the year 1996 is determined as:

$$V = 33.4\ E9\ \ Tons$$

Equation 11 is adjusted to calculate the time required to exhaust the limestone reserves, assuming that the rate of extraction remains the same, the recycling rate is assumed ot be 20 percent, and the initial volume V_0 (in 1996) is 33.4 billion tons. If the limestone reserve quantity is no longer feasible for extraction (or in other words there is no more limestone), the available reserve is equal to ten times the annual rate of consumption. Given these conditions, Equation 11 is rearranged as follows:

$$t = \frac{V_0 - V}{(1 - g)\ .\ q}$$

Substituting in the previous equation yields to:

$$t = \frac{33.4\ E9 - 10\ .\ 74\ E6}{(1 - \frac{20}{100})\ .\ 74\ E6}$$

solving for the time t

$$t = 551 \quad years$$

It is clear that increasing the percentage of the recycled material and reducing the amount of wastes will increase the value of g. This increase, will help to insure the availability of resources in the future, and extend the lifetime of natural resources.

CHAPTER 7
MODEL DEVELOPMENT AND CASE STUDY

Introduction

Data collection, data analysis, and modeling techniques were presented in the previous chapters. This information and techniques offer the knowledge needed to construct the model which can simulate the past and current construction materials consumption rates and allow for future forecasting.

This chapter will cover the model development method including the factors that influence the rate of consumption and a simulation for the past and current FDOT expenditure. This simulation projects expenditures projection, and designs an approach for managing a sustainable highway constructions program. This chapter also validates and evaluates this developed model.

Past and Current Rates of Consumption

The total sum of quantities of asphalt concrete pavement, portland cement concrete pavement, portland cement concrete for structures, and concrete used in pipelines was calculated. Chapter 4 accumulates and calculates the data on total quantities of these materials in order to monitor the limestone quantities used in highway construction and maintenance in Florida during the years 1986 to 1995. These information will be used as input data to build the model.

Selection of Variables

The general problem discussed in this section involves one dependent variable Y and a set of k independent variables X_1, X_2, ..., X_k. This section determines the best fitting regression model for describing the relationship between the Y and the X's which employs the best subset of these k independent variables.

Correlation Coefficient Matrix

In choosing variables and the regression application, these independent variables are usually not independent all (Chatfield, 84). Some of these variables may have high correlations, which produce singularity problems. Therefore, it is advisable to check the correlation matrix of the independent variables before carrying out a multiple regression so some of the variables can be excluded.

To construct the consumption model, the dependent and independent variables need definition to be used in developing the model. The model will simulate past data and forecast future dependent variable values (one of the primary objectives of this project). This dependent variable is limited to the consumed limestone quantities. Some of the independent variables influence highway construction and the decision-making for development. The influencing variables that were studied include: population, number of vehicles, miles of roads, annual miles traveled by residents, oil prices, number of houses, and tax revenue. The tax revenue is defined as taxes in this research. The past data was collected from the Florida Statistical Abstract (Florida, 1980-1995) for the years 1980 to 1995 for the purposes of the statistical analysis.

The previously mentioned independent variables were correlated to the limestone quantities that were consumed during the years 1986 to 1995 as well as the expenditures of the same duration. These variables were correlated to find the significant influence of each variable on another. The correlation matrix was obtained using the SAS PROC CORR procedure which performs advanced correlation procedures. Table 7.1 illustrates the correlation coefficient matrix.

Table 7.1 Correlation matrix of independent and dependent variables

	Population	op. Variat	Household	Taxes	Oil Prices	Roads	Miles Trav	Vehicles No	xpenditur	Lime Quant.
Population	100.00%									
Pop. Variat.	-23.79%	100.00%								
Households	99.73%	-20.98%	100.00%							
Taxes	98.81%	-15.33%	99.06%	100.00%						
Oil Prices	-81.12%	9.21%	-83.55%	-86.08%	100.00%					
Roads	96.80%	-15.85%	96.13%	94.12%	-72.32%	100.00%				
Miles Trav.	96.08%	-17.95%	95.93%	95.66%	-74.22%	98.19%	100.00%			
Vehicles No.	97.07%	-16.79%	97.82%	98.01%	-89.02%	90.08%	90.72%	100.00%		
Expenditure	88.78%	-50.79%	82.66%	81.63%	10.62%	84.33%	77.88%	91.30%	100.00%	
Lime Quant.	78.38%	-39.82%	64.19%	59.32%	-14.91%	62.32%	50.05%	71.77%	75.87%	100.00%

The limestone quantities and the expenditures are associated with the population, number of houses, total taxes revenue, miles of roads, vehicles number, and miles traveled. The oil prices, which are unpredictable, showed the minimum correlation with both limestone quantities and expenditures. The correlation analysis showed that some of the independent factors are correlated with each other; for example, the correlation of population and vehicle numbers in Florida showed a high correlation of 97.07%. Analysis incorporating all these variables was performed to obtain a preliminary model of both the consumption of limestone quantities, and the expenditures data. Preliminary models were then refined, and some of the variables were excluded to produce the final model.

Qualification of the Independent Variables

One-way analysis of variance test, ANOVA, was conducted to qualify the independent variables for linear addition in the quantities model. The two tested hypothesis are the null and the alternative hypotheses. The null hypothesis states that all the variables means are equal; the independent variables cannot be added linearly in a regression model. The alternative hypothesis supports the linear addition of the independent variables in a regression model. The hypotheses of interest are as follows:

H_o: the means of independent variables are equal

H_1: the means of independent variables are not equal

The SAS PRC GLM was used to perform the one-way ANOVA for the population, miles of roads, households number, number of vehicles, tax revenues, and miles of roads variables which will be used in the model development. For this type of tests, if the calculated F-value is greater than the critical F, at α level, then the null hypothesis is rejected. The ANOVA table is as follows:

```
                    General Linear Models Procedure

Dependent Variable: QUAN
                                 Sum of          Mean
Source                   DF     Squares        Square    F Value     Pr > F
Model                    5    1.278E+14     2.129E+13     175.18     0.0578
Error                    2    1.216E+11     1.216E+11
Uncorrected Total        7    1.279E+14
```

The F-value calculated by SAS is 175.18. The tabulated critical F at $\alpha=0.05$ is equal to 19.3. Comparing the calculated F-value to the critical F, then the null hypothesis is rejected. This is an indication that the independent variables could be added linearly in a linear regression modeling technique.

Time Index

As shown in the correlation matrix, table 7.1, the consumed limestone quantities correlate with, or depend on, some variables. Although the taxes might depend on population, they may or may not necessarily be driving force for the changes in the used limestone quantities. For the purpose of this work, the relationship among points estimates describing the distribution of population, taxes, number of vehicles, number of houses, and miles traveled as variables that directly influence the limestone quantities may be qualified.

It is important to notice that the variables liste above and the resultant limestone quantities are directly related to time. The time represented by the year, during which average representations are reported and/or calculated, acts as an index for both sides of the relationship between the limestone quantities and the variables. Therefore, the time in this analysis can be used as an index for both parts of this relationship. Time changes in any independent or dependent variables for both parts this relationship occur with changes in the time index. The time index is defined as *t* in these models.

Population

Florida is one of the most rapidly growing states in the United States (Smith & Nogle, 1996). Population is one of the significant factors which affects the highway construction trends in Florida. The past data for population was collected from the Florida Statistical Abstract (Florida, 1980-1995) for the years 1980 until 1995. These data was used to construct the model to forecast the future population in

Florida which will be used in the consumption rate model.

The univariate procedure, described in chapter 6, was used to construct the population model. Several modeling methods were used including straight line, quadratic line, logarithmic transformation, and the quadratic square transformation. The full input file for the population model are included in appendix B. The most reliable model which gave a reasonable R-Squared R^2, value was the logarithmic transformed model. Then, The population model was validated by the prediction conducted by Eileen Kalb and Stanley Smith (Kalb, 1995) and (Smith & Nogle, 1994). The population model showed a strong projection in the validation phase. Table 7.2 records the population data, and table 7.3 contains the model to forecast population. Figure 7.2 illustrates the observed and the forecasted population.

Table 7.2 Observed population in Florida

Year	**Observed**	**Model**
1980	9,747,200	*9,684,035*
1981	10,106,000	*10,049,055*
1982	10,375,300	*10,396,597*
1983	10,591,700	*10,734,669*
1984	10,982,500	*11,050,532*
1985	11,322,300	*11,364,319*
1986	11,654,100	*11,663,665*
1987	12,000,200	*11,958,932*
1988	12,327,600	*12,249,418*
1989	12,650,900	*12,534,420*
1990	12,938,100	*12,813,233*
1991	13,196,000	*13,098,247*
1992	13,242,400	*13,376,219*
1993	13,608,600	*13,646,436*
1994	13,878,900	*13,908,197*
1995	14,149,317	*14,174,979*

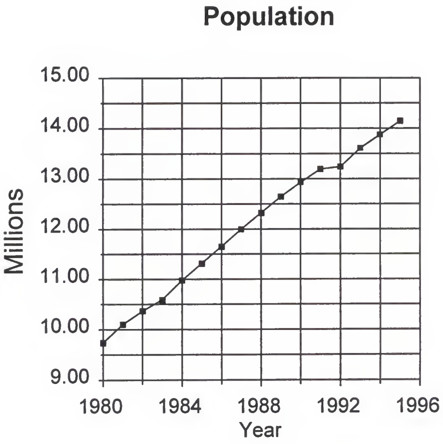

Figure 7.1 Plot to illustrate the population trend in Florida.

Table 7.3 Model to forecast the population in Florida using logarithmic transformation.

$$\boxed{\mathit{Log\ Population} = 16.039407 + 0.109113\ t - 0.062431\ t^{1.2}}$$

```
                     Analysis of Variance

                    Sum of     Mean
Source        DF    Squares    Square     F Value    Prob>F

Model          2    0.21283    0.10642     2044.701  0.0001
Error         13    0.00068    0.00005
C Total       15    0.21351

    Root MSE       0.00721     R-square       0.9968
    Dep Mean      16.29783     Adj R-sq       0.9963
    C.V.           0.04426

                         Parameter Estimates

                  Parameter      Standard
 Variable   DF     Estimate        Error          Prob > |T|

 INTERCEP    1    16.039407     0.00847131          0.0001
 TIME_IND    1     0.109113     0.01365975          0.0001
 TIME_IND2   1    -0.062431     0.01012281          0.0001
```

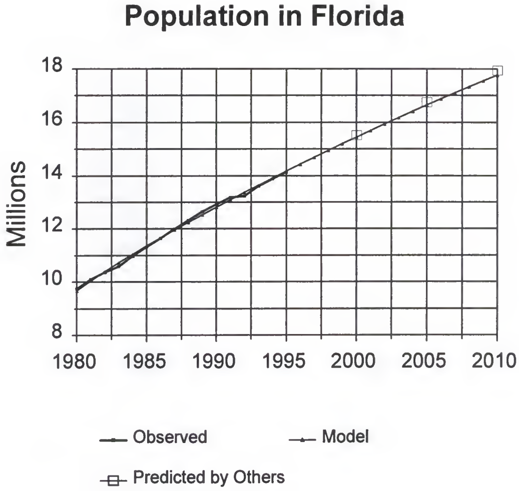

Figure 7.2 Observed and modeled population data.

Number of Vehicles

The number of vehicles in Florida is directly correlated with the population. According to the Florida Statistical Abstract (Florida, 1980-1995), there was a substantial increase in the number of vehicles between 1980 and 1994. The number of vehicles increased by about 1.7 times in a 14 years period. The number of vehicles is one of the variables that was considered to affect the highway construct and maintenance activities. These activities increase the consumption of construction materials and the rate of expenditure.

Based on the available past data, the number of vehicles was modeled as a function of old data, population and time. This vehicle model is used to construct the consumption rate which will predict future needs of raw materials, and to forecast for the future expenditures. Several methods were used to model the data of vehicles, including modeling as a straight line regression, and a logarithmic transformation. Table 7.4 illustrates the data on the number of vehicles; table 7.5 presents the selected model to forecast the future number of vehicles in Florida; and figure 7.3 plots the observed and the modeled data.

Table 7.4 A presentation of observed and modeled vehicles number.

Year	**Observed**	**Model**
80	7,797,375	*7,214,805*
81	7,887,881	*8,144,976*
82	8,622,549	*8,898,471*
83	9,064,490	*9,540,373*
84	9,444,964	*10,101,231*
85	10,827,693	*10,601,312*
86	11,651,253	*11,048,183*
87	11,738,273	*11,451,111*
88	11,997,948	*11,821,077*
89	12,276,272	*12,153,144*
90	12,465,790	*12,451,340*
91	12,706,050	*12,729,610*
92	12,911,148	*12,975,433*
93	13,041,716	*13,194,575*
94	13,125,760	*13,393,524*

Table 7.5 Illustration for the number of vehicles model.

$$\boxed{Vehicles = -58713540 + 6.979363\ Population - 1666809\ t}$$

```
                             Analysis of Variance

                          Sum of         Mean
Source          DF       Squares         Square       F Value      Prob>F

Model            2   5.1713178E13    2.5856589E13   179.528      0.0001
Error           12 1.7283064E12     144025529332
C Total         14 5.3441485E13

    Root MSE   379506.95558     R-square        0.9677
    Dep Mean 11047944.3333      Adj R-sq        0.9623
    C.V.            3.43509

                             Parameter Estimates

                      Parameter      Standard    T for H0:
Variable   DF         Estimate       Error       Parameter=0  Prob > |T|

INTERCEP    1        -58713540   16593391.280        -3.538     0.0041
POPUL       1         6.979363      1.74398545        4.002     0.0018
TIME_IND    1         -1666809   521954.76304        -3.193     0.0077
```

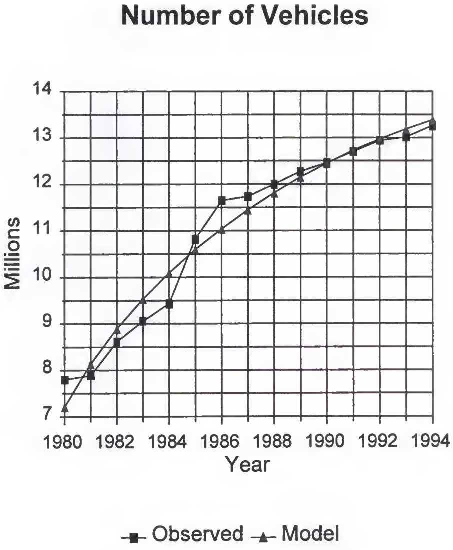

Figure 7.3 Observed and modeled vehicles numbers.

Households

Average household size can change dramatically over time. The United States Bureau of the Census (United, 1990) estimated that the average household size was 2.76 in the 1980 and 2.63 in the 1990. Average house hold size remained relatively constant since 1990.

Average household size is a good indicator of number of houses. Building new communities, which is directly related to the population, requires building of new houses. These new houses require new services and new roads.

The number of households was modeled as a function of old data, population, and time. This household model is used to construct the consumption rate which will predict the future needs of raw materials as well as to forecast for future expenditures. Several preliminary models were completed to achieve the household model. The best model to analyze the household variable in Florida is presented by the model as a function of population and time. This model predicts a reasonable average household size in the year 2010. Table 7.6 illustrates the number of households; table 7.7 presents the selected model to forecast the number of future households in Florida; and figure 7.4 plots for the observed and modeled data.

Table 7.6 Number of Households.

Year	Observed	Model
80	3,744,254	*3,680,453*
81	3,883,771	*3,867,772*
82	4,023,287	*4,040,593*
83	4,135,881	*4,205,556*
84	4,287,718	*4,352,098*
85	4,448,535	*4,496,917*
86	4,612,822	*4,629,758*
87	4,789,135	*4,759,214*
88	4,966,487	*4,884,704*
89	5,145,115	*5,005,645*
90	5,134,869	*5,121,451*
91	5,257,518	*5,242,403*
92	5,348,609	*5,357,512*
93	5,428,896	*5,466,188*
94	5,521,943	*5,567,850*

Table 7.7 Model for number of households in Florida

$$\boxed{\mathit{Households} = -4237343 + 0.829538\ \mathit{Population} - 115479\ t}$$

```
                        Analysis of Variance

                       Sum of          Mean
Source          DF    Squares         Square       F Value    Prob>F

Model            2  4.9525789E12   2.4762895E12     657.563 0.0001
Error           12  45190330895    3765860907.9
C Total         14  4.9977693E12

    Root MSE    61366.61069     R-square       0.9910
    Dep Mean 4715256.00000     Adj R-sq       0.9895
    C.V.            1.30145

                        Parameter Estimates

                   Parameter     Standard   T for H0:
Variable  DF        Estimate    Error       Parameter=0    Prob > |T|

INTERCEP   1     -4237343  2683166.0600       -1.579          0.1403
POPUL      1     0.829538    0.28200399        2.942          0.0123
TIME_IND   1      -115479  84400.547267       -1.368          0.1963
```

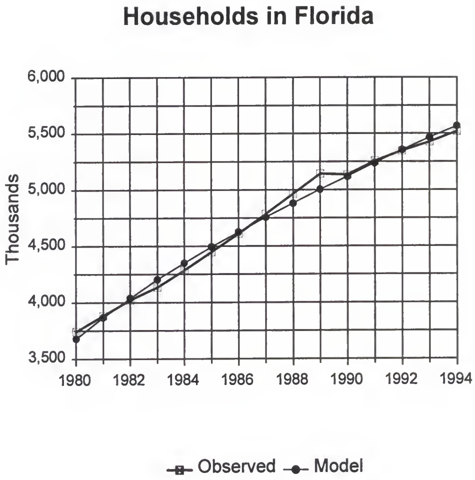

Figure 7.4 Observed and modeled households number.

Taxes

The taxes in Florida are directly connected to the population. According to the Florida Statistical Abstract (Florida, 1980-1995), there was a substantial increase in taxes between 1980 and 1994. Taxes increased about 2.7 times in a 14 years period. Taxes are used to support the building of the infrastructure including highway construction. The taxes in Florida are one of the considered variables which affect available funds and budgets used to construct and maintain highways and roads.

Based on the available past data, the taxes in Florida were modeled as a function of both old data, population and time. This taxes model is used as an independent variable in the consumption rate which will predict the future needs of raw materials, and forecast future expenditures. Several methods were used to model the available tax data, including a straight-line regression modeling, multiple regression, and a logarithmic transformation. Table 7.8 illustrates the tax dada; table 7.9 presents the selected model to forecast the future taxes in Florida; and figure 7.5 plots the observed and modeled data.

Table 7.8 Taxes in Florida.

Year	Observed (Millions)	Model Millions)
80	$10,852	$8,963
81	$9,335	$10,938
82	$12,573	$12,794
83	$13,365	$14,579
84	$15,842	$16,242
85	$17,310	$17,877
86	$20,901	$19,431
87	$20,737	$20,952
88	$23,849	$22,438
89	$25,035	$23,888
90	$25,643	$25,300
91	$25,504	$26,727
92	$27,732	$28,115
93	$29,539	$29,459

Table 7.9 Model for taxes in Florida

$$Taxes = -33678 + 0.004354\ Population + 779.083583\ t - 302.828398\ t^{1.2}$$

```
                         Analysis of Variance

                         Sum of         Mean
Source        DF        Squares        Square     F Value     Prob>F

Model          3 561932047.59 187310682.53     139.655      0.0001
Error         10 13412427.629 1341242.7629
C Total       13 575344475.21

    Root MSE     1158.12036     R-square        0.9767
    Dep Mean    19872.64286     Adj R-sq        0.9697
    C.V.            5.82771

                         Parameter Estimates

                Parameter      Standard    T for H0:
 Variable  DF   Estimate        Error     Parameter=0   Prob > |T|

 INTERCEP   1       -33678  36185.367808     -0.931        0.3739
 POPUL      1     0.004354    0.00389184      1.119        0.2894
 TIME_IND   1   779.083583  2467.6652110      0.316        0.7587
 TIME_IND2  1  -302.828398  924.76882055     -0.327        0.7501
```

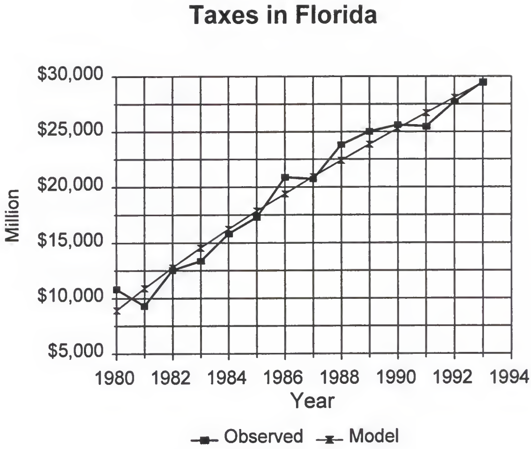

Figure 7.5 Observed and Modeled Taxes in Florida.

Miles Traveled

The rapid development in Florida attracts a number of people to move to the growing state. Population is correlated to the number of vehicles and miles traveled. The correlation matrix showed that there are significant correlations between the highway construction and maintenance, annual expenditures, and the miles traveled. The past data for miles traveled was collected from the Florida Statistical Abstract (Florida, 1980-1995) for the years 1980 until 1993. This data was used to construct the model to forecast the future miles traveled in Florida which will be used in the consumption rate model.

The multiple regression procedure was conducted to model the past data of miles traveled. This model will predict the future miles traveled to be considered as an independent variable in the construction of the material consumption model. Several regression procedures were carried out until a reasonable model was reached. These trials took into consideration miles traveled as a function of population and time, and the logarithmic transformation. Table 7.10 represents the miles traveled data. Table 7.11 provides the model with the highest R-Squared value of 0.964, and figure 7.6 is a presentation of the observed and modeled data.

Table 7.10 A presentation of miles traveled data.

Year	Observed (Millions)	Model (Millions)
80	79,002	75,532
81	76,145	76,525
82	79,498	78,428
83	71,776	81,054
84	85,745	83,867
85	88,056	87,264
86	87,273	90,836
87	93,639	94,788
88	105,319	99,053
89	108,877	103,572
90	109,997	108,296
91	113,483	113,520
92	119,868	118,877
93	120,467	124,327

Table 7.11 Model for miles traveled in Florida.

$$\text{Miles Traveled} = -166076 + 0.026126 - 21004\,t + 9603.867211\,t^{1.2}$$

```
                          Analysis of Variance

                         Sum of          Mean
Source          DF      Squares         Square        F Value      Prob>F

Model            3 3579614923.6   1193204974.5         89.360      0.0001
Error           10 133527352.74   13352735.274
C Total         13 3713142276.4

    Root MSE     3654.13947     R-square          0.9640
    Dep Mean    95653.21429     Adj R-sq          0.9533
    C.V.            3.82020

                          Parameter Estimates

                    Parameter      Standard     T for H0:
 Variable  DF        Estimate         Error   Parameter=0   Prob > |T|

 INTERCEP   1         -166073  114173.26352        -1.455       0.1764
 POPUL      1        0.026126    0.01227966         2.128       0.0593
 TIME_IND   1          -21004  7786.0584946        -2.698       0.0224
 TIME_IND2  1     9603.867211  2917.8610205         3.291       0.0081
```

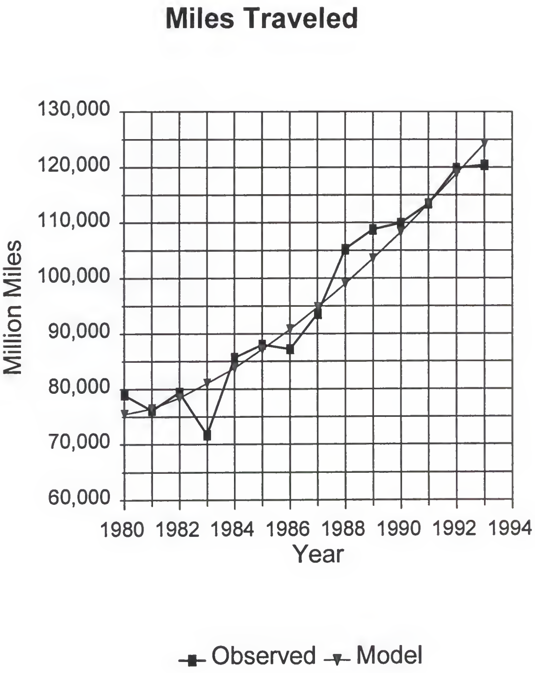

Figure 7.6 Observed and modeled miles traveled in Florida.

Road Miles

There is a significant correlation between the road miles and the population. The past data for road miles was collected from the Florida Statistical Abstract (Florida, 1980-1995) for the years 1980 to 1995. This data was used to construct the model to forecast the future roadway miles in Florida which will be used in the consumption rate model.

The multiple regression procedure was conducted to model the past data of road miles. This model will predict the future miles available to be considered as an independent variable in the construction of the material consumption model. It was noted that the road miles are in increase due to the rapid grow of Florida. This expansion is translated to more road construction and maintenance activities.

Based on the available past data, the road miles in Florida was modeled as a function of both old data, population. Table 7.12 illustrates the observed road miles data, table 7.13 presents the statistical analysis for the selected model to forecast the future miles of roads, and figure 7.7 plots the observed and the modeled data.

Table 7.12 A presentation of road milage data.

Year	Observed	Model
1980	91,699	91,699
1981	93,388	93,388
1982	95,039	95,039
1983	96,668	96,668
1984	98,249	98,249
1985	99,824	99,824
1986	101,368	101,368
1987	102,902	102,902
1988	104,426	104,426
1989	105,937	105,937
1990	107,435	107,435
1991	108,947	108,947
1992	110,443	110,443
1993	111,922	111,922
1994	113,382	113,382

Table 7.13 Statistical analysis for Road Miles in Florida.

Road Miles= 69312 + 0.002221 *Population* + 878.65463 *t*

```
                          Analysis of Variance

                                      Sum of      Mean
 Source        DF     Squares         Square    F Value     Prob>F

 Model         2  668155191.87   334077595.94  89.059      0.0001
 Error         12 45014093.058   3751174.4215
 C Total       14 713169284.93

     Root MSE     1936.79488      R-square        0.9369
     Dep Mean   102784.26667      Adj R-sq        0.9264
     C.V.            1.88433

                          Parameter Estimates

                      Parameter      Standard    T for H0:
Variable  DF  Estimate          Error      Parameter=0  Prob>|T|

 INTERCEP  1     69312      48709.318267   1.423         0.1802
 POPUL     1  0.002221     0.00511999      0.434         0.6722
 TIME_IND  1     878.654639  1538.3054868 0.571         0.5784
```

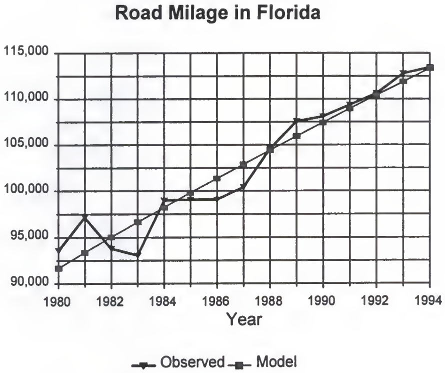

Figure 7.7 Observed and modeled road milage in Florida.

At this stage, after obtaining the independent variables in the past and the future, the following section details the construction of a model that can simulate the past data and can predict the future consumption.

Consumption Model Development

The consumption model was developed with the assistance of the SAS PROC REG procedure. This procedure produces advanced regression operation.

Preliminary model selection was made on the basis of engaging the previously discussed variables to create the final model. This selection was based on taking the best value of the coefficient of determination, R-Squared, into consideration as well as consistent future forecasting quantities. In general, it was noted that engaging more independent variables enhances the model and increase the R-Squared value. However, this model which presents a good fit for past and current data does not necessarily mean that the model will give good forecast. Therefore, fitting the model to the available data, checking the model by forecasting for the future quantities, and comparing the past and expected expenditures were necessary to obtain the optimum model. The correlation matrix (table 7.1) shows that the correlation between the past consumed limestone quantities is related to the past expenditures by a factor of 75.87%. It was important, therefore, to select a consumption model that can maintain a correlation value as close to 75% with the past expenditures.

The development of the quantities model was based on the past collected data. For the purposes of model validation and verification, not all the observed data was applied. The quantities for seven years out of the available ten years data were used in the model development, while the rest of the data were excluded for the purposes of model verification and validation.

Table 7.14 presents some trial models used for forecasting the future limestone consumption quantities, showing model number, influencing variables, and the value of the coefficient of determination, R-Squared values. Table 7.15 is an illustration for a preliminary model. The purpose of residual analysis is to verify the fundamental statistical assumptions which are made about these errors.

The residuals reflect the degree of difference between observed and predicted values which is still present after fitting the least-square model. These assumptions are: the residuals are independent, have zero mean, follow a normal distribution, and have a common variance.

Table 7.14 Listing of some models used in the quantities model.

Model Number	Number of Parameters	Parameters	Coefficient of Determination R^2
1	1	Population	0.1294
2	1	Pop. Variation	0.6835
3	2	Expenditure Time Index	0.3370
4	2	Population Time Index	0.7591
5	2	Pop. Variation Time Index	0.7626
6	3	Population Roads Time Index	0.8413
7	4	Population Roads Tax Time Index	0.8413
8	5	Population Roads Tax Miles Driven Time Index	0.8512
9	5	Population Roads Tax Houses Time Index	0.9512

Table 7.15 An Illustration for a preliminary model.

Lime_Quant = 61609255 - 5.056397 *Population* + 1548540 *t*

```
                        Analysis of Variance

                        Sum of        Mean
Source        DF       Squares       Square         F Value   Prob>F

Model          2 1.9712707E12     985635334746    6.303     0.0580
Error          4 625542802378     156385700594
C Total        6 2.5968135E12

    Root MSE   395456.31945      R-square        0.7591
    Dep Mean 4230557.14286       Adj R-sq        0.6387
    C.V.             9.34762

                              Parameter Estimates

                Parameter    Standard    T for H0:
 Variable  DF    Estimate      Error    Parameter=0   Prob >|T|

 INTERCEP   1    61609255    19550592.539  3.151        0.0345
 POPUL      1   -5.056397    1.70526205    -2.965       0.0413
 TIME_IND   1    1548540     478894.80066  3.234        0.0319
```

The most direct and most revealing way to examine a set of residuals is to graph the residuals versus the dependent and independent variables. Figure 7.8 is a graph of residuals versus used limestone quantities when engaging the population and the time independent variables for constructing the model. It is clearly noted that the variance increases as the dependent variable, the quantities, decreases.

Correlation tests for residuals were carried out using the SAS DURBIN-WATSON procedure. This test can detect the autocorrelation between the residuals. If autocorrelation is found, then a transformation of the data is recommended. The two hypothesis here are as follows:

H_0: The residuals are independent

H_1: The residuals are dependent

The H_0 hypothesis is accepted when output d is greater than the tabulate value $d_{U,\alpha}$. Most of the DURBIN-WATSON tests showed considerable residual independence, therefore, transforming the data was not necessary for constructing the quantities model.

Figures 7.9, 7.10, 7.11, 7.12, 7.13, and 7.14 give the residual plots for the independent variables: population, number of vehicles, road miles, taxes, households, and miles traveled. The residual analysis of these independent variables shows a great deal of independence for the residuals.

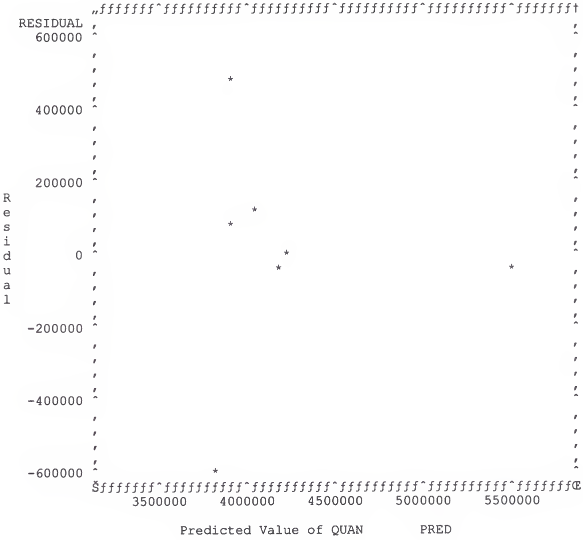

Figure 7.8 Residual plot of used limestone quantities, using population and time as independent variables.

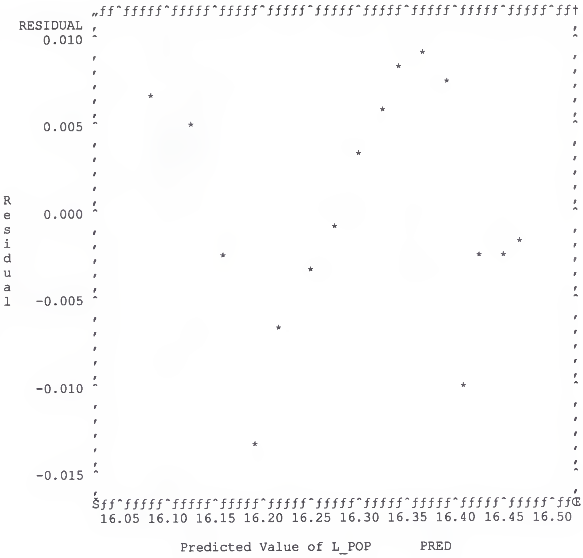

Figure 7.9 Residual plot of population variable.

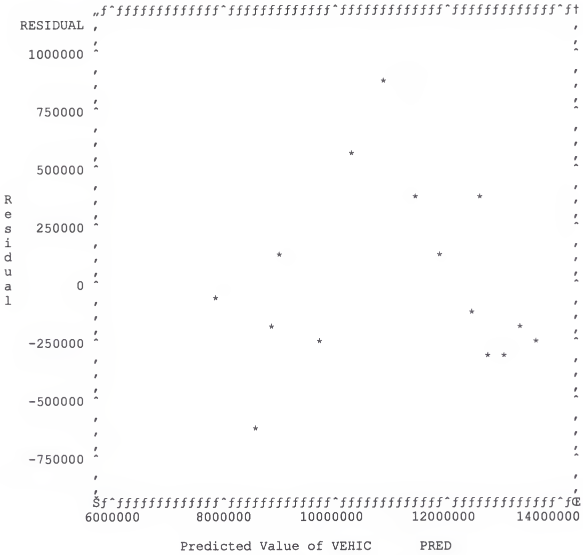

Figure 7.10 Residual plot of number of vehicles variable.

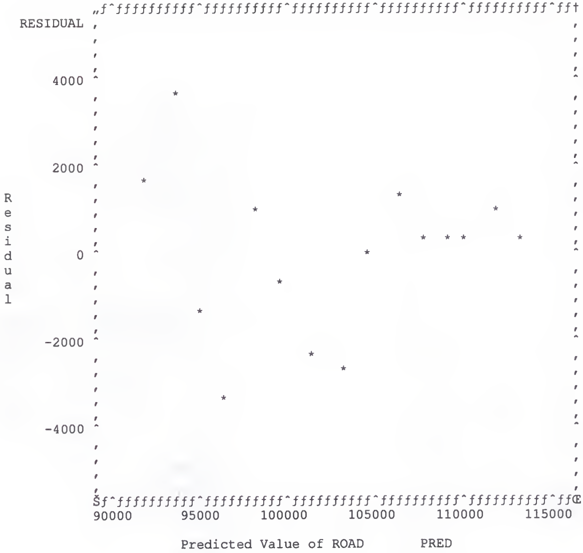

Figure 7.11 Residual plot of road miles variable.

```
           „ƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒ†
  RESIDUAL ‚                                                           ‚
           ‚                                                           ‚
           ‚                                                           ‚
           ‚                                                           ‚
      2000 ˆ                                                           ˆ
           ‚                                                           ‚
           ‚                                *                          ‚
           ‚                                                           ‚
           ‚           *                                               ‚
           ‚                                        *                  ‚
      1000 ˆ                                                           ˆ
           ‚                                                           ‚
R          ‚                                            *              ‚
e          ‚                                                           ‚
s          ‚                                                           ‚
i          ‚                                                   *   *   ‚
d        0 ˆ                         *                                 ˆ
u          ‚                  *                                        ‚
a          ‚                             *      *          *           ‚
l          ‚                    *                                      ‚
           ‚                                                           ‚
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     -1000 ˆ                                                           ˆ
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     -2000 ˆ               *                                           ˆ
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           5000       10000      15000      20000      25000      30000

                      Predicted Value of TAX        PRED
```

Figure 7.12 Residual plot of tax variable.

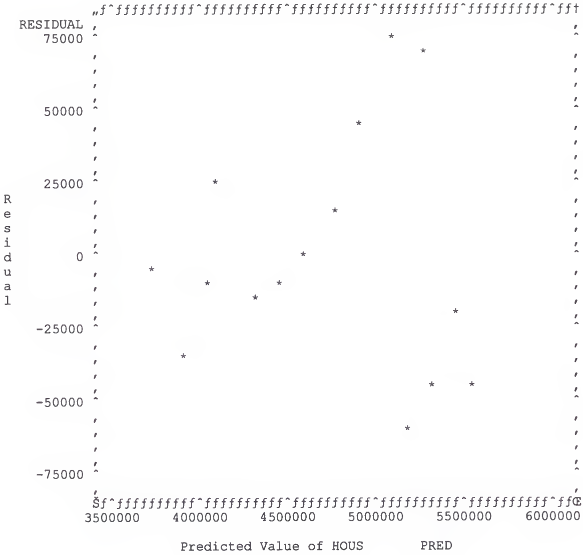


Figure 7.13 Residual plot of households variable.

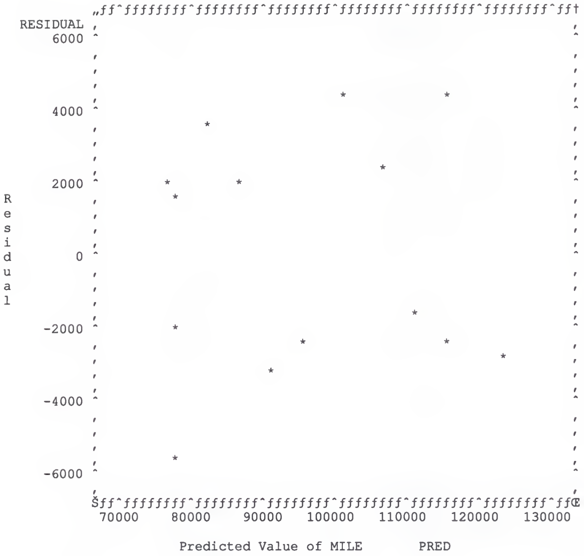


Figure 7.14 Residual plot of households variable.

Figure 7.15 presents some of the suggested quantities models and their independent variables. These preliminary models simulate the observed limestone quantities for the years 1986 until 1992. Figure 7.16 present the same models while forecasting for the future limestone quantities.

The final step in the regression and model development was to calculate the parameter estimates for the final model variables. Figure 7.17 presents the final model to simulate the past, present, and forecast the future limestone quantities that will be used in highway construction. The highest R^2 obtained was 0.9512 for model number 9. The final model is includes the population, roads miles, taxes, households, and time variables. The statistical results for the final model is shown in table 7.16

Forecasting for Future Expenditures

The total expenditure for FDOT is around one billion dollar. Analyzing the past expenditures and material quantities will support the prediction for future sustainability.

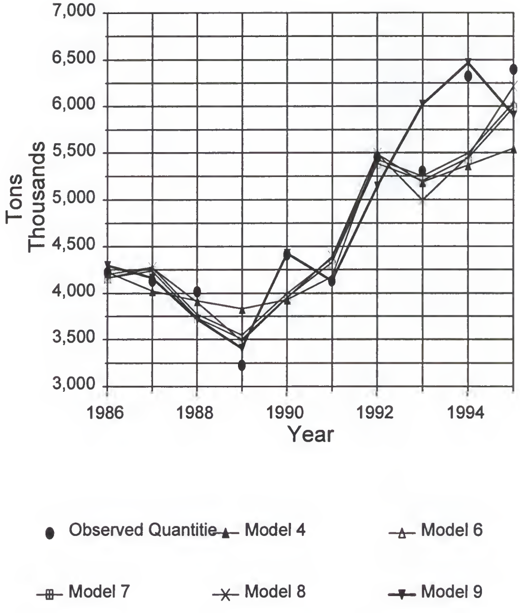


Figure 7.15 A presentation for preliminary limestone quantities models.

Model 4	f (Population, Time Index)
Model 6	f (Population, Roads, Time Index)
Model 7	f (Population, Roads, Tax, Time Index)
Model 8	f (Population, Roads, Tax, Miles, Time Index)
Model 9	f (Population, Roads, Tax, Houses, Time Index)

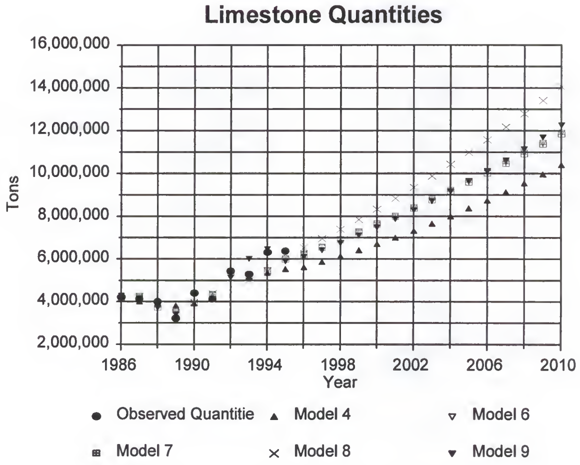


Figure 7.16 Preliminary models to forecast the consumption of limestone quantities.

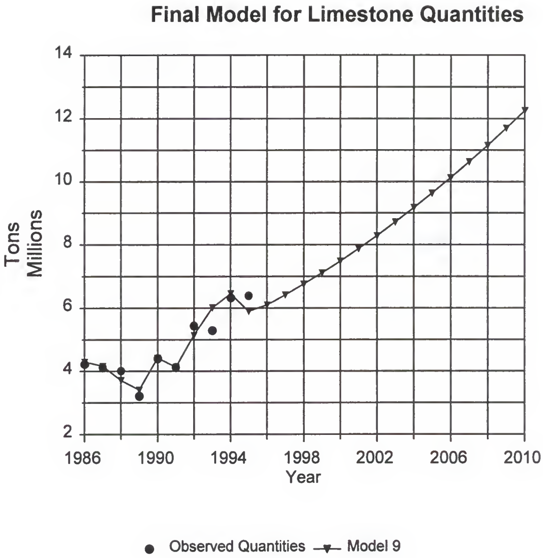


Figure 7.17 Final model for limestone quantities

Table 7.16 Final model for limestone quantities.

Lime_Quant = 55981549 - 2.766358 Population + 188.033129
Road_Miles + 301 Taxes - 9.928699 Houses +
1435939 *t*

```
                         Analysis of Variance

                            Sum of         Mean
Source          DF         Squares       Square       F Value     Prob>F

Model            5 2.4700193E12  494003863167       3.896     0.3660
Error            1 126794156035  126794156035
C Total          6 2.5968135E12

    Root MSE   356081.67046      R-square       0.9512
    Dep Mean  4230557.14286      Adj R-sq       0.7070
    C.V.            8.41690

                             Parameter Estimates

                    Parameter      Standard     T for H0:
 Variable   DF      Estimate          Error    Parameter=0   prob >|T|

 INTERCEP    1      55981549   18728858.409        2.989        0.2055
 POPUL       1     -2.766358     2.11377311       -1.309        0.4154
 ROAD        1    188.033129   325.98126275        0.577        0.6669
 TAX         1      0.000301     0.00028004        1.075        0.4770
 HOUS        1     -9.928699     6.61785013        1.500        0.3743
 TIME_IND    1       1435939   476668.07970        3.012        0.2040
```

This projection will act in the quantities model verification as well as the development of suggested strategies and guidelines for obtaining a sustainable construction.

To forecast for future expenditures, the SAS PROC REG procedure was used as in the quantities model. The development of a model to forecast future expenditures was based on the past collected data, as well as independent variables such as population, taxes, road miles, and time variables.

Preliminary model selection was made on the basis of engaging the previously discussed variables to obtain the final model. This selection was based on taking into consideration the best value of the coefficient of determination, R-Squared. The steps for checking and validating the model were preformed by obtaining the data on the expected expenditures for the next five years from FDOT, and comparing these values with the model output.

Table 7.17 presents some trial models used for forecasting future expenditures and showing the model number, acting variables, and the value of the coefficient of determination, R^2, R-Squared value.

Figure 7.18 present some of the suggested expenditures models and the associated independent variables. Also figure 7.19 shows these models These preliminary models while forecasting future expenditures.

The calculation of the parameter estimates for the final model variables is the final step in the regression and the model development. Figure 7.19 presents the final model to simulate past and present data and forecast future expenditures in highway construction. The highest R^2 obtained was 0.9953 for model number 6. The final model includes the population, roads miles, and taxes as independent variables. Table 7.18 is an illustration of the final model.

Model Validation

As previously mentioned in this chapter, the data used in validating the consumption model is the data of consumed limestone quantities for the years 1993 to 1995. This data already existed, but was excluded intentionally for the validation purpose.

The proposed model is used to predict the limestone quantities used during the years 1993 to 1995 as shown in table 7.19. Generally the precision of the model appeared related to the coefficient of determination R^2. The higher the R^2 value, the more accurate the value predicted. The correlation between the consumed limestone quantities and its association with the total annual expenditures is used to validate the model.

Table 7.17 Listing of some models used in the Expenditures model.

Model Number	Number of Parameters	Parameters	Coefficient of Determination R^2
1	1	Population	0.8365
2	2	Pop. Variation	0.1969
3	3	Population Time Index	0.8548
4	4	Pop. Variation Time Index	0.8684
5	4	Population Roads Time Index	0.8723
6	4	Population Roads Taxes Time Index	0.9953
7	4	Population Roads Taxes Vehicles Number	0.9847
8	5	Population Roads Taxes Vehicles Number Houses	0.9848
9	6	Population Roads Taxes Vehicles Number Houses Miles Driven	0.8951

Model 3	f (Population, Time Index)
Model 5	f (Population, Roads, Time Index)
Model 6	f (Population, Roads, Tax, Time Index)
Model 7	f (Population, Roads, Tax, Vehicles)
Model 8	f (Population, Roads, Tax, Vehicles, Houses,)
Model 9	f (Population, Roads, Tax, Vehicles, House, Miles)

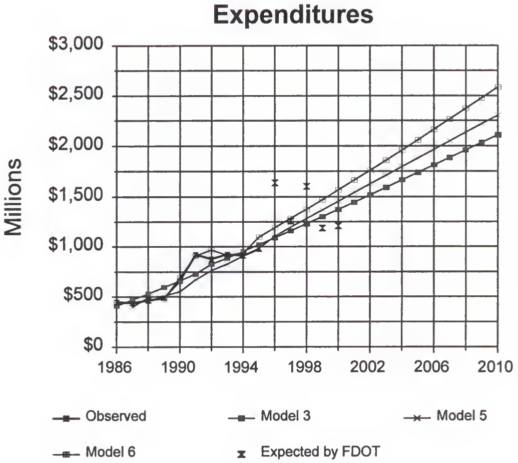


Figure 7.18 Some preliminary models to forecast future expenditures.

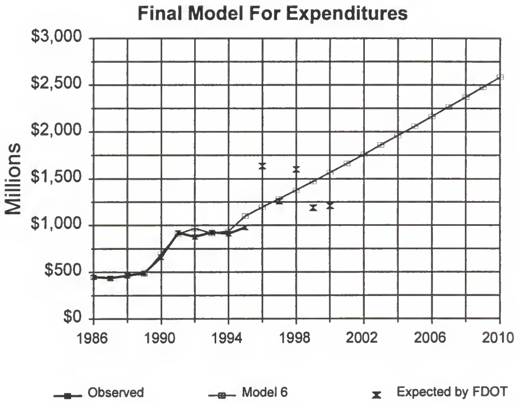


Figure 7.19 Final model for expenditures.

Table 7.18 Statistical analysis for the final expenditures model.

$$\mathit{Expenditure} = 561347945 + 231.182407\ \mathit{Population} - 65613\ \mathit{Roads} - 81658\ \mathit{Taxes} + 229257136\ t$$

```
                          Analysis of Variance

                              Sum of          Mean
Source           DF          Squares        Square     F Value      Prob>F

Model             4 3.4636529E17   8.6591323E16     158.189      0.0008
Error             3 1.6421791E15   5.4739303E14
C Total           7 3.4800747E17

    Root MSE 23396431.9870      R-square        0.9953
    Dep Mean 654985440.250      Adj R-sq        0.9890
    C.V.           3.57205

                            Parameter Estimates

                    Parameter      Standard    T for H0:
 Variable  DF        Estimate         Error   Parameter=0     Prob >|T|

 INTERCEP   1      5691347945  1191912903.9        4.775         0.0175
 POPUL      1      231.182407  137.19243217        1.685         0.1906
 ROAD       1          -65613  11353.328087       -5.779         0.0103
 TAX        1       -0.081658    0.01153018       -6.909         0.0062
 TIME_IND   1       229257136  31165291.066        7.356         0.0052
```

The SAS PROC CORR is used to find the correlation between the limestone quantities and the expenditures as shown in table 7.1. The correlation between the different modeled quantities and the associated expenditures were calculated in table 7.20. Model 9 has a correlation factor of 77.5% with the annual expenditures, which is the nearest correlation value between the observed limestone quantities and the expenditure as obtained in table 7.1.

The quantities model and the expenditures model appear to provide reasonable presentation and prediction of the limestone quantities, as a nonrenewable natural resources, and the associated expenditures. However, these are models, and as such they can never make exact prediction.

Table 7.19 Observed and modeled limestone quantities.

Year	***Observed Quantities***	***Modeled Quantities***
1986	4,234,707	*4,299,149*
1987	4,140,523	*4,168,098*
1988	4,024,581	*3,720,803*
1989	3,237,074	*3,409,920*
1990	4,425,512	*4,431,243*
1991	4,143,826	*4,134,649*
1992	5,461,765	*5,145,491*
1993	5,313,148	*6,023,807*
1994	6,335,123	*6,469,219*
1995	6,404,689	*5,909,591*
1996		*6,107,930*
1997		*6,424,355*
1998		*6,760,348*
1999		*7,115,611*
2000		*7,489,923*
2001		*7,883,126*
2002		*8,295,116*
2003		*8,725,832*
2004		*9,175,251*
2005		*9,643,379*
2006		*10,130,247*
2007		*10,635,911*
2008		*11,160,442*
2009		*11,703,926*
2010		*12,266,460*

Table 7.20 Correlation coefficients for different quantities models and expenditures.

	Observed Expenditures	Modeled Expenditures	Model 6	Model 7	Model 8	Model 9
Observed Expenditures	1.000	0.9807	0.82108	0.8197	0.7975	0.7752
Modeled Expenditures	0.9807	1.0000	0.8825	0.8813	0.8758	0.8078
Model 6	0.8210	0.8825	1.0000	0.9998	0.9906	0.9142
Model 7	0.8197	0.8813	0.9998	1.0000	0.9907	0.9139
Model 8	0.7975	0.8758	0.9906	0.9907	1.0000	0.8682
Model 9	0.7752	0.8078	0.9142	0.9139	0.8682	1.0000

CHAPTER 8
SUSTAINABLE MANAGEMENT APPROACH

Introduction

Managing the supply and demand of natural resources to reduce waste is the key factor for a successful sustainable program. A number of researchers found that the quantities of waste generated in Brazil at construction sites form approximately 20%, by weight, of all materials delivered to sites (Carven & Okraglik, 1994).

Causes of Construction Waste

A sustainable management is one that minimizes or avoids construction waste. A number of reasons to cause construction waste in different phases are:

Design Phase

Wastes are generated due to errors in contract documents. The designers may make design mistakes in applying the specifications.

Procurement Phase

One source of waste in materials is errors in ordering. Errors include ordering materials with different specifications, over-ordering quantities, and under-ordering quantities. Moreover, errors by suppliers as a cause of waste in materials cannot be ignored.

Materials Handling

Material waste in this phase is due to damage during transportation to site and the materials handling on site. Inappropriate storage may cause damage to or deterioration of materials.

Operation Phase

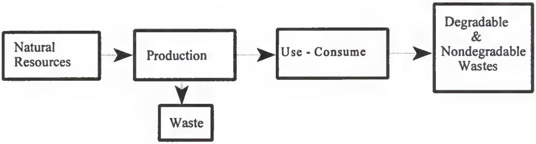
Errors by laborers generate waste in this phase. Waste also could be generated by of equipment malfunction, bad weather, accidents, and use of incorrect material in replacement activity.

Environmental attitudes and rising disposal costs are forcing communities to target wastes for management other than disposal. The next section of this chapter discusses material recovery to minimize wastes.

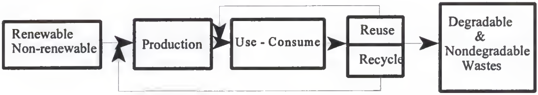
Materials Recovery

In order for the development of the environment to become more sustainable, traditional patterns of production and consumption need to be modified. Incorporating reuse and recycling strategies, among others, will aid in sustainable development.

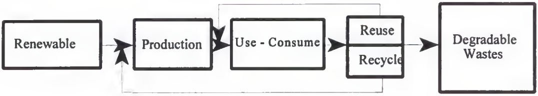
The material life cycle is shown in figures 8.1, a, b, and c. In figure 8.1a, the materials' life cycle is based on the single use of the material, then dispose it in a form of waste. This cycle represents the unsustainable model. Figure 8.1b is a representation of a most realistic sustainable model. Here, the materials have a semi-cyclical production and consumption cycle which incorporate the reuse and recycling of used materials. The input materials are of the renewable and nonrenewable types. The waste in this model has both degradable and nondegradable components. Figure 8.1c represents the ideal production consumption model where the input materials are of the renewable resources type, and the output waste is degradable. Aggregates constitute 70 to 100 percent of the solid volume of the pavement structure,, and thus play an important role in the optimization of materials in transportation construction. The next section discusses the production and consumption of natural resource that support highway construction.



a. Linear life cycle model.



b. Semi-cyclic life cycle model.



c. Cyclic life cycle model.

Figure 8.1 Different models of life cycle of materials.

Materials Production and Consumption

Production and consumption for three construction materials are discussed in this section. According to the Bureau of Mines’ Mineral Industry Surveys (Mineral, 1984-1995), an estimated 1.35 billion short tons of crushed stones were produced and consumed in the United States in 1994. Production and consumption during 1994 exceeded 9.7 percent more than of 1993's. This tonnage represents the highest production level ever recorded in the United States, indicating a continued increase in the demand for construction aggregates in 1994. Of this quantity, 83 million short tons were produced in Florida, a 17.3% increase compared to production in 1993. About 85% of the crushed stone production continued to be limestone and dolomite. Quantities of crushed stone production in Florida are illustrated in figure 8.2. The Florida Department of Transportation FDOT, throughout the selected research activities, consumed approximately 6.5 million ton of limestone in 1994, which form about 9% of the total limestone produced in Florida.

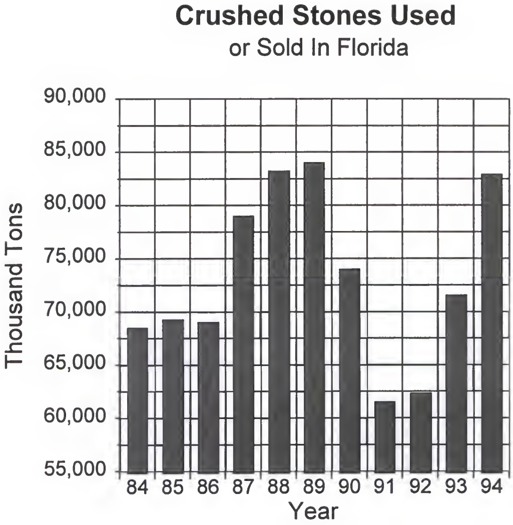


Figure 8.2 Crushed stones quantities used or sold in Florida.

Approximately 1.1 billion short tons of sand and gravel were produced and consumed in the United States in 1994. Production and consumption exceeded 50 million tons, by 5.2% in 1994. It was estimated that about 26 million short ton were produced and consumed in Florida in 1994 (An increase of 0.5 million tons over 1993). Figure 8.3 records quantities of sand and gravel production in Florida. Selected research activities consumed approximately 1 million tons of the total production in Florida.

The Bureau of Mines estimated that the U.S. produced and consumed 130 million short tons of cement in 1994. Production and consumption during 1994 exceeded about 10 percent more than in 1993, indicating the increase in demand for construction materials in 1994. The cement production was estimated to be 4.5 million tons in Florida in 1994 with an increase of 0.6 million tons more than in 1993. The increase in cement production and use in Florida is an indication of the increase in construction activities. Figure 8.4 shows the quantities of cement production. Highway construction activities consumed approximately 119 thousand tons of the total quantities produced in Florida.

Some resources are used intensively in highway construction while others are not. The following factors determine their usage: material suitable characteristics, cost, availability, and the existence of alternatives. The indexing methodology identifies the importance of some of the natural resources in highway construction.

Index of Nonrenewable Materials Importance

The index is "an indicator" , in which statistical analysis, is generally associated with pure numbers which measure relative change from a recognized norm. More specifically, index numbers are artificial measurements which relate one or more real measurements to an arbitrary value.

One of the most important reasons for the universal popularity of index numbers is that index numbers usually consist of real numbers of rarely more than four digits. This property facilitates both the written and the oral communication of data.

The index of the nonrenewable materials' importance (INMI) was performed on some of the resources used in highway construction. The quantities of these resources are calculated from the FDOT contract history. These resources include: limestone, sand, gravel, portland cement, and asphalt cement.

The rate of change in consumption for these materials is calculated for 1995 given that the year 1993 was considered as a datum. A score between the numbers 1 and 5 was given for the rate of change of consumption: for example, the higher the rate of consumption is, the higher the score. Table 8.1 shows that the highest rate of consumption is calculated for sand, therefore, the score for sand was given the value of 5. In contrast, the lowest rate of consumption was calculated for protland cement; therefore, its score was given as the number 1.

The number of alternatives that can substitute for nonrenewable material was considered. The availability of more resource alternatives tends to increase the confidence in the resource's life cycle. These alternatives for each natural resource were identified in the literature survey phase. If the resource has no alternative, it is assigned a score value of 4. If the resource has less than 3 alternatives, it is assigned a score value of 3. Similarly, between 3 and 6 alternatives, the score was 2, between 6 and 9 alternatives, the score was 1. When the resource has more than 9 alternatives, then the given score value was zero. Also each of the nonrenewable materials was evaluated according to its average cost. The higher the cost per ton, the higher the score value. The total score for each resource is then calculated.

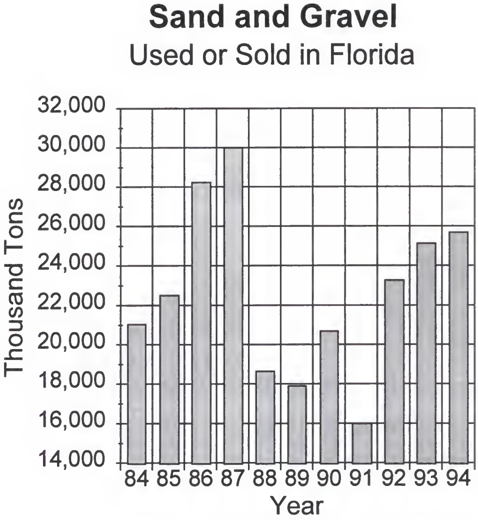


Figure 8.3 Illustration of sand and gravel quantities used or sold in Florida.

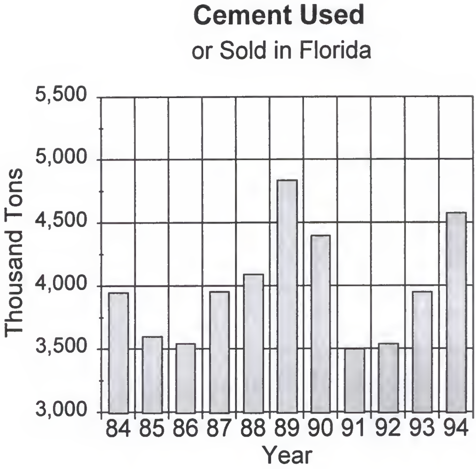


Figure 8.4 Cement quantities used or sold in Florida.

The highest total score indicates that the assigned material is the most important one to support highway construction, and so on. Table 8.1 illustrates the INMI showing that the most important material in the highway construction is asphalt cement in first place, followed by limestone.

Recycling and Savings

Technological advances, economic hard times and environmental awareness are paving the way for significantly greater recycling and use of old materials in road construction, repair, and maintenance the United States.

The quantities and percentages of recycling, adding waste materials and by-product to substitute conventional materials are according to the Florida Department of Transportation Standard Specifications for Road and Bridge Construction (Florida, 1991). The following section of this chapter demonstrates examples of savings in portland cement, asphalt cement, and limestone savings. Savings in portland cement is an indirect indication of saving in limestone.

Using of Fly Ash

Section 345-2.2 of the FDOT Standard Specifications mention that fly ash may be used to replace up to 20 percent by weight of cement content in concrete classes used in structures. In addition, fly ash may be used to replace not more than 20 percent by weight of the cement used in concrete pavement.

Fly ash can substitute up to 93.6 lbs of cement used in concrete, which yield to 2.53 percent of savings in limestone material per each ton of concrete. The FDOT contract history was used to calculate the total quantities for concrete that were used in structures and pavement. Table 8.2 shows the total limestone quantities, new and saved materials for the years 1986 to 1995. It was noted that the total limestone saved was between 0.32 and 0.68 percent when using fly ash.

Using Reclaimed Asphalt Concrete Pavement

According to section 331-2.2.4 of FDOT standard Specifications, reclaimed asphalt pavement RAP shall not exceed 60 percent by weight of total aggregates for asphalt base course nor more than 50 percent by weight of total aggregates for structural and leveling course. Reclaimed asphalt pavement shall not be used in friction courses.

The total saved limestone quantities were calculated between 28 and 31 percent of the total quantities when using reclaimed asphalt concrete. Using RAP not only saves the limestone material but also saves asphalt cement binder. Table 8.3 shows the total limestone quantities, new materials, and saved materials for the years 1986 to 1995.

Table 8.1 An illustration for the INMI showing the order of importance of highway construction Resources.

Description	***LImestone***	***Score***	***Sand***	***Score***	***Gravel***	***Score***	***Portland Cement***	***Score***	***Asphalt Cement***	***Score***
Alternatives	Blast Furnace Slag Steel Slag Ceramics C&D Debris Rec. Asph. Concrete Rec. Conc. Pav. Incinerators Phosphogypsum Chat	1	Glass and Ceramics C&D Debris Rec. Conc. Pav. Foundary Sand	2	Glass and Ceramics Plastics C&D Debris Rec. Concrete Pav.	2	Blast Furnace Sla Steel Slag Fly Ash Rice Husk Ash	2	Rubber Plastics Sulphur Roof Shingles Wood Lignin	2
Rate of Consumptio Change in last 3 yea	20.58%	4	60.03%	5	12.51%	2	12.28%	1	15.66%	3
Average Cost	$13.00	3	$8.00	1	$12.00	2	$112.00	4	$214.00	5
Total Score		8		8		6		7		10
Total Rank		***2***		***2***		***4***		***3***		***1***

Table 8.2 Using Fly Ash in Highway Construction.

Year	Original Quantities	New Materials	Material Saved	Percentage Saved
86	4,227,450	4,202,089	25,361	0.60%
87	4,132,523	4,112,428	20,095	0.49%
88	4,016,980	3,998,146	18,834	0.47%
89	3,229,850	3,207,756	22,094	0.68%
90	4,417,512	4,389,196	28,316	0.64%
91	4,135,826	4,110,807	25,019	0.60%
92	5,453,765	5,425,919	27,846	0.51%
93	5,305,148	5,277,796	27,352	0.52%
94	6,327,123	6,306,920	20,202	0.32%
95	6,396,689	6,367,146	29,543	0.46%

Table 8.3 New and saved materials in Tons when using RAP.

Year	Original Quantities	New Limestone Materials	Limestone Saved	Asph. Cement Saved	Percentage Lime Saved
86	4,227,450	3,014,076	1,213,374	72,802	28.70%
87	4,132,523	2,960,894	1,171,628	70,298	28.35%
88	4,016,980	2,850,905	1,166,075	69,965	29.03%
89	3,229,850	2,247,964	981,886	58,913	30.40%
90	4,417,512	3,110,321	1,307,191	78,431	29.59%
91	4,135,826	3,168,444	967,382	58,043	23.39%
92	5,453,765	4,200,927	1,252,837	75,170	22.97%
93	5,305,148	3,874,896	1,430,253	85,815	26.96%
94	6,327,123	4,356,341	1,970,781	118,247	31.15%
95	6,396,689	4,542,094	1,854,594	111,276	28.99%

Figure 8.5 illustrates the observed consumed quantities and the new and saved materials when using RAP and Fly ash.

Economic and energy analyses were conducted on a project in Florida to determine the cost and energy savings attained by using RAP in hot mix recycling (Schweyer, 1980). The project is described as an overlaying for a 33.3 miles of one lane road. The cost for recycling is about 75 percent of the cost for conventional hot mix overlay. The 25 percent savings incurred by recycling was achieved by 35 percent savings in asphalt cement, and 53 percent savings in materials and operating costs to produce asphalt concrete hot mix. The total savings would provide approximately 13 lane miles of additional recycled pavement for the equivalent cost of conventional paving.

The summary of energy savings is presented in table 8.4, indicating that the recycling project consumed only 45.8 percent of energy required for conventional hot mix overlay. Approximately 50 percent of the energy savings is attributed to the reduction in new aggregate and asphalt cement.

Using Ground Tire Rubber

Section 336-3 of the FDOT Standard Specifications require that ground rubber shall be thoroughly mixed and

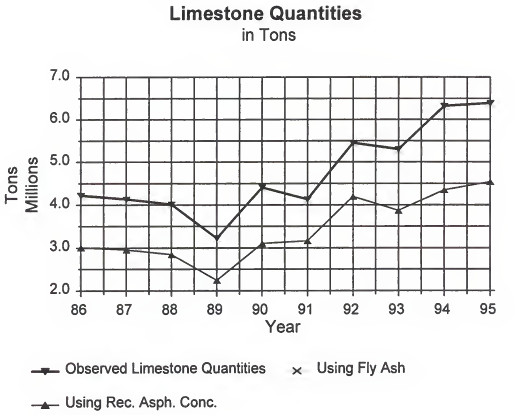


Figure 8.5 Observed and saved limestone quantities when using RAP and Fly ash.

Table 8.4 Energy savings when using RAP.

Operation	Using Conventional Materials		Using Recycled Materials	
	BTU/Ton	Percent Energy Requirement	BTU/Ton	Percent Energy Requirement
Milling	---	---	32,178	9.2
Materials	203,600	33.5	37,765	10.7
Plant Operations	358,120	58.9	260,824	74.2
Field Operations	20,260	3.3	20,813	5.9
Shoulder Work	---	4.3	---	---
Total	***581,980***	***100.0***	***351,580***	***100.0***

reacted with percentage up to 20 percent by weight of asphalt cement depending on friction course type.

Ground rubber can substitute up to 24 lbs of asphalt cement used for each ton of concrete pavement. The FDOT contract history was used to calculate the total quantities of asphalt cement that were used in pavement. Total limestone quantities, corresponding asphalt cement material, and saved materials were shown in table 8.5.

Table 8.6 illustrates the total observed limestone quantities, total saved quantities when using RAP in addition to fly ash, and saved quantities in asphalt cement when recycling the ground rubber and using RAP.

The next section of this chapter demonstrates the previous analysis to visualize and monitor the consumption and savings in nonrenewable resources.

Future Savings

The developed model was used to forecast the future consumption of limestone. The median of saved quantities for the years 1986 to 1995 was calculated as 29.45 percent of the total limestone quantities for the activities included in this research. This percentage is assumed to be constant, if not increasing, to calculate the limestone

Table 8.5 Asphalt cement quantities when using ground rubber.

Year	Original Asph. Cem. Quant.	New Materials	Asph. Cement Saved	Percentage Saved
86	215,230	172,184	43,046	20.00%
87	222,106	177,685	44,421	20.00%
88	218,521	174,817	43,704	20.00%
89	163,589	130,871	32,718	20.00%
90	218,624	174,900	43,725	20.00%
91	209,676	167,741	41,935	20.00%
92	281,714	225,371	56,343	20.00%
93	273,952	219,162	54,790	20.00%
94	352,022	281,618	70,404	20.00%
95	334,558	267,647	66,912	20.00%

Table 8.6 Past consumed and saved quantities.

Year	Observed Quantities	New Limestone Materials	Limestone Saved	Asph. Cement Saved	Percentage Lime Saved	Asph. Cem Saved
86	4,227,450	**2,988,715**	1,238,735	115,848	29.30%	2.74%
87	4,132,523	**2,940,800**	1,191,723	114,719	28.84%	2.78%
88	4,016,980	**2,832,071**	1,184,909	113,669	29.50%	2.83%
89	3,229,850	**2,225,871**	1,003,979	91,631	31.08%	2.84%
90	4,417,512	**3,082,005**	1,335,507	122,156	30.23%	2.77%
91	4,135,826	**3,143,425**	992,401	99,978	24.00%	2.42%
92	5,453,765	**4,173,081**	1,280,684	131,513	23.48%	2.41%
93	5,305,148	**3,847,544**	1,457,605	140,606	27.48%	2.65%
94	6,327,123	**4,336,139**	1,990,983	188,651	31.47%	2.98%
95	6,396,689	**4,512,552**	1,884,137	178,187	29.45%	2.79%
Avegrage Savings					***29.45%***	2.72%

quantities saved in the future. The savings in asphalt cement, calculated for the years 1986 to 1995, shows an average of 2.72 percent. This value is assumed to be constant to calculate the future savings in asphalt cement.

Table 8.7 demonstrates the forecasted consumed quantities in both limestone and asphalt cement. The total forecasted quantities, based on the management system currently used, will be approaching 12.5 million tons of used limestone by the year 2010. The recycling approach yields an average gain of 29.45 percent. This gain leads to a huge reduction in the consumption of limestone as a representative of nonrenewable natural resources. Table 8.7 and figure 8.6 show the used and saved amounts in the future. An accumulation procedure was performed on used quantities in both cases, with and without recycling. Table 8.8 and figure 8.7 illustrate these quantities showing that the total used limestone quantities are approximately 134 million tons for the years 1996 to 2010. When recycling, the accumulated quantities in 2010 yielded 93 million tons of used limestone, which is a saving of 39 million tons. This savings could be translated to savings of 3.6 million tons in asphalt cement used in highway construction, and consequently, saving in funds.

Recycling not only has an effect on the consumed quantities of construction materials but also on the cost. The FDOT estimated that about 23% of the annual budgets are assigned to resurfacing activities[1]. According to Schweyer (Schweyer, 1980), approximately 25% cost savings are achieved when using RAP in hot mix asphalt overlaying. Table 8.9 and figure 8.8 illustrate the cost savings from incorporating RAP. Using RAP can save up to $90 million in the year 2000, and approximately $150 million in 2010.

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[1] Fax transmission receive from Mr. William R. Kynoch--FDOT budget officer.

Table 8.7 Expected consumed and saved quantities.

Year	Forecasted Quantities	New Lime Materials	Limestone Saved	Asph. Cement Saved	Percent Lime Saved	% Asph Cem. Saved
1996	**6,107,930**	4,309,144	**1,798,785**	**166,104**	**29.45%**	**2.72%**
1997	**6,424,355**	4,532,382	**1,891,973**	**174,709**		
1998	**6,760,348**	4,769,425	**1,990,922**	**183,846**		
1999	**7,115,611**	5,020,063	**2,095,547**	**193,507**		
2000	**7,489,923**	5,284,140	**2,205,782**	**203,687**		
2001	**7,883,126**	5,561,545	**2,321,581**	**214,380**		
2002	**8,295,116**	5,852,204	**2,442,912**	**225,584**		
2003	**8,725,832**	6,156,075	**2,569,758**	**237,297**		
2004	**9,175,251**	6,473,140	**2,702,111**	**249,519**		
2005	**9,643,379**	6,803,404	**2,839,975**	**262,249**		
2006	**10,130,247**	7,146,890	**2,983,358**	**275,490**		
2007	**10,635,911**	7,503,636	**3,132,276**	**289,241**		
2008	**11,160,442**	7,873,692	**3,286,750**	**303,506**		
2009	**11,703,926**	8,257,120	**3,446,806**	**318,286**		
2010	**12,266,460**	8,653,988	**3,612,473**	**333,584**		

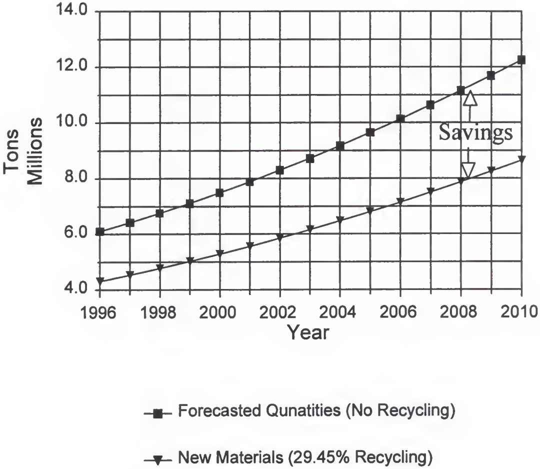

Figure 8.6 Expected limestone consumption and savings associated with recycling.

Table 8.8 A presentation for accumulated quantities used when not recycling versus recycling.

Accumulated Quantities - No Recycling versus Recycling

Year	No Recycling (Forecasted)	New Limestone Materials	Limestone Saved	Asph. Cement Saved
1996	6,107,930	4,309,144	1,798,785	166,104
1997	12,532,284	8,841,527	3,690,758	340,813
1998	19,292,632	13,610,952	5,681,680	524,659
1999	26,408,243	18,631,016	7,777,228	718,166
2000	33,898,166	23,915,156	9,983,010	921,853
2001	41,781,292	29,476,701	12,304,590	1,136,233
2002	50,076,408	35,328,906	14,747,502	1,361,816
2003	58,802,240	41,484,981	17,317,260	1,599,113
2004	67,977,491	47,958,120	20,019,371	1,848,632
2005	77,620,870	54,761,524	22,859,346	2,110,882
2006	87,751,117	61,908,413	25,842,704	2,386,371
2007	98,387,029	69,412,049	28,974,980	2,675,612
2008	109,547,471	77,285,741	32,261,730	2,979,118
2009	121,251,397	85,542,860	35,708,536	3,297,404
2010	133,517,857	94,196,848	39,321,009	3,630,987

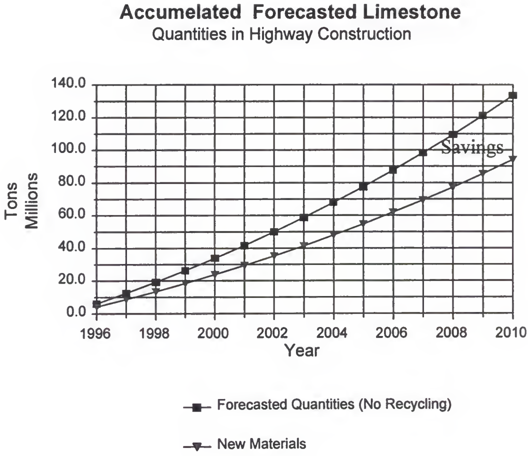

Figure 8.7 Accumulated quantities when using no recycling versus using recycling.

Table 8.9 Expected future cost savings when using RAP.

Year	$ for resurfacing	RAP Savings	Expend. After Savings
1996	$262,949,124	$65,737,281	$1,034,004,995
1997	$282,972,197	$70,743,049	$1,124,480,240
1998	$317,090,919	$79,272,730	$1,206,964,528
1999	$338,661,307	$84,665,327	$1,293,990,843
2000	$360,537,890	$90,134,473	$1,382,305,992
2001	$382,713,887	$95,678,472	$1,471,877,573
2002	$405,183,419	$101,295,855	$1,562,677,569
2003	$427,941,377	$106,985,344	$1,654,681,694
2004	$450,983,317	$112,745,829	$1,747,868,853
2005	$474,305,366	$118,576,341	$1,842,220,689
2006	$497,904,145	$124,476,036	$1,937,721,205
2007	$521,776,707	$130,444,177	$2,034,356,453
2008	$545,920,476	$136,480,119	$2,132,114,257
2009	$570,333,206	$142,583,302	$2,230,983,987
2010	$595,012,933	$148,753,233	$2,330,956,359

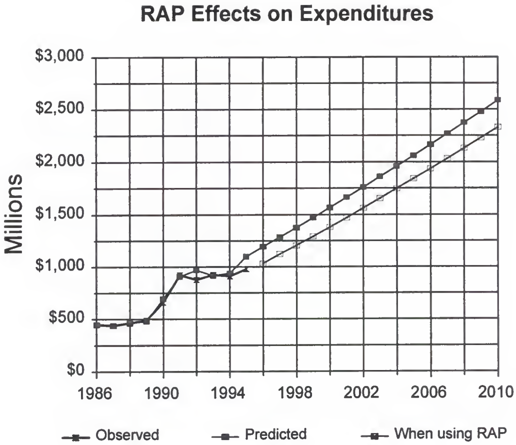

Figure 8.8 Future savings when using RAP.

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Survey of Highway Agencies SHA indicates that all state highway agencies are first considering RAP followed by fly ash by-product in their recycling programs. The SHA reveals that 91 percent of the states that responded are using RAP in structural concrete course, and about 31 percent indicated its suitability in friction course of the asphalt concrete pavement. The RAP is competitive with the conventional materials because of it costs less and performs equally. Eighty percent of the states responding use fly ash and 90 percent of these states use fly ash as a substitute for the portland cement material in the portland cement concrete pavement. The scrap tires are used by 42 percent of the responding states as an additive to replace the asphalt cement in the friction and structural courses. About 14 percent of the states are using scrap tires in subgrade. The SHA indicates that furnace slag is used as course aggregates in all pavement courses. At least 42 percent of the responding states are using slag in their construction program. Of these states, 73 percent indicate that it is equal in cost, and 60 percent indicate that it has an equal performance, when compared to the conventional materials.

Although highway construction consumes multi-millions of tons of materials annually, not all waste materials and by-products can be incorporated into these processes. Considering the total number of responses to the issue of recycling for all pavement courses, 27 percent of the states agencies are using some kind of recycling in the structural course; 22 percent are performing recycling in pavement base; 17.5 percent in friction course; 17 percent in portland cement pavement; and 16.5 percent are recycling pavement subgrade.

The ranking of wastes and by-products, using the SHA data, indicates that the RAP, ranked number one, is the most reliable material for recycling. Most of the agencies indicate that RAP costs less, and has an equal performance when compared to conventional materials. The fly ash comes in second to RAP as a reliable material for recycling.

Some major factors that could affect the suitability of using wastes in highway construction are the engineering characteristics and economical competition with conventional materials.

The statistical analysis proves the cost-effectiveness of using recycling in highway construction. The null hypothesis was rejected indicating that there is a significant dependency between the type of waste and the cost.

The statistical analysis was performed to check the affect of using recycling on engineering performances. The result was to reject the null hypothesis and accept the alternative one. This result is an indication of a significant association between the type of waste and the overall engineering performance of the final product.

The amount limestone consumed indicates that the demand for this natural resources is on increase. The FDOT consumed 6.4 million tons of limestone in 1995, an increase of 21 percent over that of 1993, and 51 percent of that over 1986. This increase is due to the expansion of the construction and maintenance activities.

Based on the current methods of consuming and recycling, the simple mechanistic model developed in chapter 6 suggests that limestone as a natural resources is available for more than 500 years, but should still be considered exhaustible.

At this stage, after quantifying the limestone quantities consumed in the past, the model that simulates the past data and forecasts future limestone consumption is developed. The variables that have the most effects on the model behavior are the population, miles of roads, annual taxes, and household numbers. The chosen model to represent the past quantities and to forecast the future ones has a Coefficient of Determination, R^2, value of 0.9512. The model demonstrates that the limestone consumption will approach 12.5 million tons by 2010 if the same methods of construction are used. The multiple regression procedure demonstrates that it is a valid and useful approach to simulate and forecast future consumption.

The research of this project concentrates on quantities of limestone consumed in highway construction. However, the modeling concept could be applied to other construction categories such as building construction. Both highway and building construction have the same principles, despite of the difference in influencing factors.

Modeling for future expenditures demonstrates a high confidence level when compared to the expected expenditures for the next 5 years that were conducted by the FDOT. The variables that showed the greatest influence on the model formulation were: population, road miles, and taxes as functions of time. The coefficient of determination for the expenditures model is 0.9953.

The Index of the Nonrenewable Materials Importance show that the most important material in highway construction, out of five chosen materials, is the asphalt cement. The second position is shared by the limestone and the sand. Portland cement is in the third position and gravel is in the fourth. The management procedure conducted for the first two materials shows that by using recycling, a total savings of 39 million tons of limestone, and 3.6 million tones of asphalt cement can be expected in 2010.

Using RAP can provide approximately $90 million in cost savings in the year 2000. This saving is expected to be up to $150 million in the year 2010.

Recommendation

Markets for waste materials and by-products being used, or being considered for use, such as highway construction materials should exist.

Local, county, or municipal construction projects should involve the use of more wastes and by-products where traffic volumes are low, budgets are tight, and procedures are more flexible.

Efforts should be made to find a more economical way to use scrap tires in asphalt.

Highway construction and environmental agencies should get the benefits of the inventory and quantities of appropriate waste materials and by-products generated or stockpiled within their states.

Highway construction standard specifications should be modified to incorporate more abundant, less quality waste and by-products materials as a substitute for conventional materials.

The milled asphalt concrete pavement should be of the DOT's properties instead of the contractors.

The use of already disposed waste materials is significant. Some of these wastes show a high potential as substitutes for conventional materials, and therefore, preserve exhaustible resources.

Comprehensive research is needed to identify and categorize factors that could influence the consumption of different resources. If reliable lists of influencing factors were available, appropriate data collection and model development would be more feasible.

The development of a model to forecast the future consumption of different natural resources, other than limestone, is needed. This model could be based on a nation wide data collection.

Comprehensive research to identify the advantages of using phosphogypsum is still needed.

The percentage of RAP that can be added as a substitute for conventional materials is still low. Evaluation for new process that can increase the use of 100 percent RAP is needed.

Further investigation is suggested to determine the use of RAP in the friction course.

More research is needed to identify the use of adding sulphur to substitute asphalt cement.

Advantages should be rewarded to contractors who will use, or are using, recycling and by-product materials in the bidding process. Bidding should not only be limited to matching the specifications with the lowest available prices, but environmental and preservation factors should be included.

Impose green taxes on contractors and construction activities that harm the environment and produce wastes. These taxes should also be imposed on products or activities that pollute, deplete, or degrade the environment.

Concrete block pavement could be used in parking lots, roads, airfields, and ports. This type of pavement has a longer life and needs little maintenance.

Development of a more complicated model to predict the available time for natural resources is suggested, taking into account the variables of recycling and consumption of natural resources as a function of time.

Using the "Emergy" concept to compare and evaluate the pavement processes which use conventional materials, versus those that use recycled materials.

Minimize and optimize the energy consumed in highway construction. Minimizing the consumption of energy help to preserve fossil fuel, reduce the amount of green gas produced.

The process of variable selection and modeling techniques are strong candidates for an expert system. The current artificial intelligence technology used in consumption modeling would significantly support sustainable development methodologies.

Even though acceptable results are obtained with multiple regression analysis using the linear model, different statistical procedure need to be tried and results compared.

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APPENDIX A

DATA COLLECTION FORMS

Survey of Waste Materials and Their Uses in Highway Construction

Please indicate by checking the boxes which materials are being reused in your construction program.

	Asphaltic Concrete Pavement		Portland Cement Pavement	Pavement Base	Subgrade
	Friction course	*Structural course*			
Reclaimed Asphalt Conc.	☐	☐	☐	☐	☐
Scrap Tires	☐	☐	☐	☐	☐
Blast Furnace Slag	☐	☐	☐	☐	☐
Steel Slag	☐	☐	☐	☐	☐
Bottom Ash	☐	☐	☐	☐	☐
Fly Ash	☐	☐	☐	☐	☐
Combustion Ash	☐	☐	☐	☐	☐
Mining Waste	☐	☐	☐	☐	☐
Used Motor Oil	☐	☐	☐	☐	☐
Building Rubble	☐	☐	☐	☐	☐
Waste Glass	☐	☐	☐	☐	☐
Used Motor Oil	☐	☐	☐	☐	☐
Waste Paper	☐	☐	☐	☐	☐
Roof Shingles	☐	☐	☐	☐	☐
Plastics	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐

Survey of Waste Materials and Their Economic Performance in Highway Construction

Please indicate by checking the boxes the effect of adding waste materials to the item's overall cost.

	More cost	Equal cost	Less cost
Reclaimed Paving Material	☐	☐	☐
Scrap Tires	☐	☐	☐
Blast Furnace Slag	☐	☐	☐
Steel Slag	☐	☐	☐
Bottom Ash	☐	☐	☐
Fly Ash	☐	☐	☐
Combustion Ash	☐	☐	☐
Mining Waste	☐	☐	☐
Used Motor Oil	☐	☐	☐
Building Rubble	☐	☐	☐
Waste Glass	☐	☐	☐
Used Motor Oil	☐	☐	☐
Waste Paper	☐	☐	☐
Roof Shingles	☐	☐	☐
Plastics	☐	☐	☐
Others	☐	☐	☐

Survey of Using Waste Materials and their Engineering Performance in Highway Construction

Please indicate by checking the boxes the effect of adding waste materials to item's engineering performance.

	Better	Equal	Worse
Reclaimed Asphalt Concrete	☐	☐	☐
Scrap Tires	☐	☐	☐
Blast Furnace Slag	☐	☐	☐
Steel Slag	☐	☐	☐
Bottom Ash	☐	☐	☐
Fly Ash	☐	☐	☐
Combustion Ash	☐	☐	☐
Mining Waste	☐	☐	☐
Used Motor Oil	☐	☐	☐
Building Rubble	☐	☐	☐
Waste Glass	☐	☐	☐
Used Motor Oil	☐	☐	☐
Waste Paper	☐	☐	☐
Roof Shingles	☐	☐	☐
Plastics	☐	☐	☐
Others	☐	☐	☐

APPENDIX B

SAS PROGRAM SOURCE CODE

The following source code is to model the independent variables that were used to obtain the quantities model and to forecast for the expenditures.

```
/* THIS FILE IS TO FORECAST THE POPULATION IN FLORIDA */
/* DATA ARE FROM THE YEAR 1980 UNTIL 1995 */
OPTION LS=72;DATA POPUL;
 INPUT POPUL TIME;

TIME2=TIME**1.1;
L_POP=LOG(POPUL);
S_POP=POPUL**.25;
/* NOTE: TIME2=TIME**1.1 GAVE THE BEST MATCH FOR EXISTED PREDICTED */
/* DATA FOR THE YEAR 2010                              */
CARDS;
9747200    1
10106000   2
10375300   3
10591700   4
10982500   5
11322300   6
11654100   7
12000200   8
12327600   9
12650900   10
12938100   11
13196000   12
13242400   13
13608600   14
13878900   15
14149317   16
.        17
.        18
.        19
.        20
.        21
.        22
.        23
.        24
.        25
.        26
.        27
.        28
.        29
.        30
.        31
.        32
PROC REG DATA=POPUL;
MODEL POPUL=TIME  TIME2 /P CLM CLI DW;
PLOT RESIDUAL.*PREDICTED.='*';
TITLE 'USING A TIME AND POWERED TIME FIT POPULATION THE DATA';
RUN;
PROC REG DATA=POPUL;
MODEL POPUL=TIME  /P CLM CLI DW;
TITLE 'USING A STRAIGHT LINE TO FIT POPULATION DATA';
PLOT RESIDUAL.*PREDICTED.='*';
```

```
RUN;
PROC REG DATA=POPUL;
MODEL L_POP=TIME TIME2 /P CLM CLI DW;
TITLE 'USING LOGARITHMIC TRANSFORMED POPULATION TO FIT THE DATA';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=POPUL;
MODEL S_POP=TIME TIME2 /P CLM CLI DW;
TITLE 'USING THE QUADRATIC ROOT FOR POPULATION TO FIT THE DATA';
PLOT RESIDUAL.*PREDICTED.='*';
PROC PLOT DATA=POPUL;
PLOT POPUL*TIME='+';
RUN;

***************************************************************
***************************************************************
/* THIS FILE IS TO FORECAST THE HOUSEHOLDS IN FLORIDA */
/* DATA ARE FROM THE YEAR I980 UNTILL I994 */
TITLE FORECASTING FOR HOUSEHOLDS UP TO YEAR 2010 IN FLORIDA;
OPTION LS=72;DATA HOUSE;
INPUT HOUS POPUL TIME;
TIME2=TIME**I.2;
/* NOTE: TIME2=TIME**1.2 GAVE THE BEST MATCH FOR EXISTED PREDICTED */
/* DATA FOR THE YEAR 20I0                               */
L_HOUS=LOG(HOUS);
CARDS;
 3744254   9747200   1
 3883771   10106000  2
 4023287   10375300  3
 4I35881   10591700  4
 42877I8   10982500  5
 4448535   11322300  6
 4612822   I1654100  7
 4789135   12000200  8
 4966487   12327600  9
 5145II5   12650900  10
 5I34869   12938I00  II
 5257518   I3I96000  I2
 5348609   13242400  13
 5428896   13608600  I4
 552I943   13878900  I5
.       I4I493I7  16
PROC REG DATA=HOUSE;
MODEL HOUS=POPUL TIME  TIME2/P CLM CLI DW;
PLOT RESIDUAL.*PREDICTED.='*';
TITLE 'USING A POPULATION ANE POWERED TIME EQUATION TO FIT THE HOUSING
DATA';
RUN;
PROC REG DATA=HOUSE;
MODEL HOUS = POPUL TIME/P CLM CLI DW;
PLOT RESIDUAL.*PREDICTED.='*';
```

```
TITLE 'USING POPULATION AND TIME TO FIT THE HOUSING DATA';
RUN;
PROC REG DATA=HOUSE;
MODEL L_HOUS=POPUL TIME  TIME2/P CLM CLI DW;
PLOT RESIDUAL.*PREDICTED.='*';
TITLE 'USING A THE LOG TRANSFORMATION TO FIT THE HOUSING DATA';
RUN;

PROC PLOT DATA=HOUSE;
PLOT POPUL*TIME='+';
RUN;

************************************************************
************************************************************


/* THIS FILE IS TO FORECAST THE VEHICLES IN FLORIDA */
/* DATA ARE FROM THE YEAR 1980 UNTIL 1994 */
TITLE FORECASTING FOR VEHICLES IN FLORIDA UP TO YEAR 2010;
OPTION LS=72;
DATA VEHICL;
INPUT VEHIC POPUL TIME;
TIME2=TIME**1.2;
L_VEHIC=LOG(VEHIC);
CARDS;
7797375    9747200   1
7887881    10106000  2
8622549    10375300  3
9064490    10591700  4
9444964    10982500  5
10827693   11322300  6
11651253   11654100  7
11738276   12000200  8
11997948   12327600  9
12276272   12650900  10
12465790   12938100  11
12706050   13196000  12
12941148   13242400  13
13021716   13608600  14
13275760   13878900  15
.          14149317  16

PROC REG  DATA=VEHICL;
MODEL VEHIC=POPUL /P CLM CLI DW;
TITLE 'USING POPULATION TO MODEL THE VEHICLES NUMBER';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG  DATA=VEHICL;
MODEL VEHIC=POPUL TIME/P CLM CLI DW;
TITLE 'USING POPULATION AND TIME TO MODEL THE VEHICLES NUMBER';
PLOT RESIDUAL.*PREDICTED.='*';
```

```
RUN;

PROC REG  DATA=VEHICL;
MODEL VEHIC=POPUL TIME TIME2/P CLM CLI DW;
TITLE 'USING POPULATION AND POWERED TIME TO MODEL THE VEHICLES NUMBER';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;


PROC REG  DATA=VEHICL;
MODEL L_VEHIC=POPUL TIME2/P CLM CLI DW;
TITLE 'USING A LOG TRANSFORMATION TO MODEL THE VEHICLES NUMBER';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;
OUTPUT OUT=VEHICL1;
PROC PLOT DATA=VEHICL1;
PLOT VEHIC*TIME='+';
RUN;

/* THIS FILE IS TO FORECAST THE ROADS IN FLORIDA */
/* DATA ARE FROM THE YEAR 1980 UNTIL 1994 */
TITLE FORECASTING FOR ROADS IN FLORIDA UP TO YEAR 2010;
OPTION LS=72;
DATA ROADS;
INPUT ROAD POPUL TIME;
TIME2=TIME**1.2;
L_ROAD=LOG(ROAD);
CARDS;
93582    9747200   1
97186    10106000  2
93797    10375300  3
93074    10591700  4
98984    10982500  5
99071    11322300  6
99074    11654100  7
100423   12000200  8
104589   12327600  9
107589   12650900  10
108095   12938100  11
109374   13196000  12
110640   13242400  13
112808   13608600  14
113478   13878900  15
.        14149317  16

PROC REG  DATA=ROADS;
MODEL ROAD= POPUL TIME TIME2/P CLM CLI DW;
TITLE 'USING A POPULATION AND POWERED TIME TO MODEL ROADS';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG  DATA=ROADS;
```

```
MODEL ROAD=POPUL TIME/P CLM CLI DW;
TITLE 'USING A POPULATION AND TIME TO MODEL THE ROADS';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG  DATA=ROADS;
MODEL L_ROAD=POPUL TIME TIME2/P CLM CLI DW;
TITLE 'USING A LOG TRANSFORMATION AND QUADRATIC';
TITLE2 'EQUATION TO MODEL THE ROADS';
PLOT RESIDUAL.*PREDICTED.='*';
RUN;
OUTPUT OUT=ROAD1;
PROC PLOT DATA=ROAD1;
PLOT ROAD*TIME;
RUN;

/* THIS FILE IS TO FORECAST THE INCOMETAX IN FLORIDA */
/* DATA ARE FROM THE YEAR 1980 UNTIL 1994 */
/* TAXES DATA ARE IN MILLIONS          */
TITLE FORCASTING FOR INCOMETAX IN FLORIDA UP TO YEAR 2010;
OPTION LS=72;
DATA TAX; INPUT TAX POPUL TIME;
TIME2=TIME**1.2;
L_TAX=LOG(TAX);
CARDS;
10852    9747200  1
9335     10106000  2
12573    10375300  3
13365    10591700  4
15842    10982500  5
17310    11322300  6
20901    11654100  7
20737    12000200  8
23849    12327600  9
25035    12650900  10
25643    12938100  11
25504    13196000  12
27732    13242400  13
29539    13608600  14
.        13878900  15
.        14149317  16
PROC REG  DATA=TAX;
 MODEL TAX=TIME POPUL TIME2/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING A POPULATION AND POWERED TIME TO MODEL THE TAXS';
RUN;

PROC REG  DATA=TAX;
 MODEL TAX=POPUL TIME/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING POPULATION AND TIME TO MODEL TAXS';
RUN;
```

```
PROC REG  DATA=TAX;
 MODEL L_TAX=POPUL TIME TIME2/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING A LOG TRANSFORMATION TO MODEL TAXS';
RUN;

PROC PLOT DATA=TAX;
 PLOT TAX*TIME='+';
RUN;

****************************************************************
****************************************************************

/* THIS FILE IS TO FORECAST THE MILE TRAVELED IN FLORIDA */
/* DATA ARE FROM THE YEAR 1980 UNTIL 1994 */
TITLE FORECASTING FOR MILES TRAVELED IN FLORIDA UP TO YEAR 2010;
OPTION LS=72;
DATA MILES; INPUT MILE POPUL TIME;
TIME2=TIME**1.2;
L_MILE=LOG(MILE);
CARDS;

/* ******************************** */
/* ****  MILES ARE IN MILLIONS *** */
/* ******************************** */
 79002   9747200    1
 76145   10106000   2
 79498   10375300   3
 71776   10591700   4
 85745   10982500   5
 88056   11322300   6
 87273   11654100   7
 93639   12000200   8
 105319  12327600   9
 108877  12650900   10
 109997  12938100   11
 113483  13196000   12
 119868  13242400   13
 120467  13608600   14
 .        13878900  15
 .        14149317  16
PROC REG  DATA=MILES;
 MODEL MILE=TIME POPUL TIME2/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING A POPULATION AND POWERED TIME TO MODEL MILES TRAVELED';
RUN;

PROC REG  DATA=MILES;
 MODEL MILE=POPUL TIME/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING POPULATION AND TIME TO MODEL MILES TRAVELED';
RUN;
```

```
PROC REG  DATA=MILES;
 MODEL L_MILE=POPUL TIME TIME2/P CLM CLI DW;
 PLOT RESIDUAL.*PREDICTED.='*';
 TITLE 'USING A LOG TRANSFORMATION TO MODEL TAXS';
RUN;

PROC PLOT DATA=TAX;
 PLOT MILE*TIME='+';
RUN;

QUIT;
```

The following code is to model the limestone quantities model. This model will be able to simulate the past and current, and to forecast for the future consumed quantities.

```
/*   THIS FILE TO MODEL AND FORECAST THE FUTURE FDOT LIMESTONE      */
/*   QUANTITIES BASED ON POPULATION, EXPENDITURE, HOUSEHOLDS,       */
/*   ROADS, VEHICLES NUMBER, AND MILES TRAVELED.                  */
/*   DATA USED IS STARTING FROM 1986 UNTIL 1992                */

/**********************************************************************/
/*********** THE YEARS 93-95 ARE NOT INCLUDED, THEY WERE    **********/
/*********** EXCLUDED INTENTIONALLY FOR THE MODEL VALIDATION **********/
/**********************************************************************/

TITLE 'MODEL TO PREDICT THE FUTURE LIMESTONE QUANTITIES';
OPTION LS=72;
DATA QUANT; INPUT POPUL  DEL_POP ROAD TAX VEHIC HOUS MILE EXP QUAN TIME;
L_QUAN=LOG(QUAN);
CARDS;
11654100  331800  99074   20901E6  11651253 4612822  87273   450320608  4227449  1
12000200  346100  100423  23849E6  11738276 4789135  93639   440010159  4132522  2
12327600  327400  104589  23849E6  11997948 4966487  105319  463795359  4016980  3
12650900  323300  107589  25035E6  12276272 5145115  108877  492772724  3229849  4
12938100  287200  108095  25643E6  12465790 5134869  109997  662207456  4417511  5
13196000  257900  109374  25504E6  12706050 5257518  113483  925154890  4135825  6
13242400  46400   110640  27732E6  12941148 5348609  119868  878728735  5453764  7
PROC CORR;

/**********************************************************************/
/***********                                             **********/
/***********            STARTING THE REGRESSION ANALYSIS            **********/
/***********                                             **********/
/**********************************************************************/

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL  / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING  REGRESSION INCLUDING';
 TITLE2 'POPULATION  VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
 RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=DEL_POP / P CLM CLI DW ;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=EXP TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'EXPENDITURE, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
```

```
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=DEL_POP TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAX, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX MILE TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAX, VEHICLES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX HOUS TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITIES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, HOUSES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX VEHIC HOUS TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITIES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, HOUSES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX VEHIC HOUS MILE TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES,  HOUSES, MILES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;
/****************************************************************/
/*********    USING LOGARITHMIC TRANSFORMATION          ************/
/****************************************************************/

PROC REG DATA=QUANT;
 MODEL L_QUAN=POPUL  / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING  REGRESSION INCLUDING';
 TITLE2 'POPULATION  VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
 RUN;
PROC REG DATA=QUANT;
 MODEL L_QUAN=DEL_POP / P CLM CLI DW ;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL L_QUAN=EXP TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'EXPENDITURE, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL L_QUAN=POPUL ROAD TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL L_QUAN=POPUL ROAD TAX TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAX, AND TIME VARIABLES';
```

```
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL L_QUAN=POPUL ROAD TAX MILE TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAX, VEHICLES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=QUANT;
 MODEL L_QUAN=POPUL ROAD TAX VEHIC HOUS TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LIME QUANTITIES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, HOUSES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;


PROC REG DATA=QUANT;
 MODEL QUAN=POPUL ROAD TAX VEHIC HOUS MILE TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES,  HOUSES, MILES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

QUIT;
```

The following code is to model the expenditures. This model will be able to simulate the past, current, and to forecast for the future FDOT expenditures.

```
/*   THIS FILE TO MODEL AND FORECAST THE FUTURE FDOT EXPENDITURES   */
/*   BASED ON POPULATION, HOUSEHOLDS, ROADS, TAXES                  */
/*   VEHICLES NUMBER, AND MILES TRAVELED.                           */
/*   DATA USED IS STARTING FROM 1986 UNTIL 1995                     */

TITLE 'MODEL TO PREDICT THE FUTURE EXPENDITURE FOR THE FDOT';
OPTION LS=72;
DATA EXPEND; INPUT POPUL  DEL_POP ROAD TAX VEHIC HOUS MILE EXP TIME;
L_EXP=LOG(EXP);
CARDS;
11654100 331800 99074  20901000000 11651253 4612822 87273   450320608  1
12000200 346100 100423 23849000000 11738276 4789135 93639   340010159  2
12327600 327400 104589 23849000000 11997948 4966487 105319  463795359  3
12650900 323300 107589 25035000000 12276272 5145115 108877  492772724  4
12938100 287200 108095 25643000000 12465790 5134869 109997  662207456  5
13196000 257900 109374 25504000000 12706050 5257518 113483  925154890  6
13242400 46400  110640 27732000000 12941148 5348609 119868  878728735  7
13608600 366200 112808 29539000000 13021716 5428896 120467  926893591  8
13878900 270300 113478    .        13275760 5521943   .     912184765  9
14146317 270417    .      .            .        .     .     941080489  10

PROC CORR;

/******************************************************************************/
/************                                                 **************/
/************      STARTING THE REGRESSION ANALYSIS              **************/
/************                                                 **************/
/******************************************************************************/

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL  / P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING  REGRESSION INCLUDING';
 TITLE2 'POPULATION  VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
 RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=DEL_POP / P CLM CLI DW ;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING  REGRESSION INCLUDING';
 TITLE2 'POPULATION AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
 RUN;
```

```
PROC REG DATA=EXPEND;
 MODEL EXP=DEL_POP TIME/ P CLM CLI DW ;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TAX TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TAX HOUS TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, HOUSES, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TAX VEHIC/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, AND VEHICLS VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TAX VEHIC HOUS/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, AND HOUSES VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;


PROC REG DATA=EXPEND;
 MODEL EXP=POPUL ROAD TAX VEHIC HOUS MILE/ P CLM CLI DW;
 TITLE 'MODEL FOR EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, VEHICLES,  HOUSES, AND MILES VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

/* ************************************************************* */
/* **********    CONSIDERING LOGARITHMIC TRANSFORMATION     *********** */
/* ************************************************************* */

PROC REG DATA=EXPEND;
 MODEL L_EXP=POPUL  / P CLM CLI DW;
 TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION  VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
 RUN;
PROC REG DATA=EXPEND;
 MODEL L_EXP=DEL_POP / P CLM CLI DW ;
 TITLE 'MODEL FRO LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION VARIATION VARIABLE';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;
PROC REG DATA=EXPEND;
 MODEL L_EXP=POPUL TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, AND TIME  VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;
PROC REG DATA=EXPEND;
 MODEL L_EXP=POPUL ROAD TIME / P CLM CLI DW;
 TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
 MODEL L_EXP=POPUL ROAD TAX TIME/ P CLM CLI DW;
 TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, AND TIME VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;


PROC REG DATA=EXPEND;
 MODEL L_EXP=POPUL ROAD TAX VEHIC / P CLM CLI DW;
 TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
 TITLE2 'POPULATION, ROADS, TAXS, AND VEHICLES VARIABLES';
```

```
PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
  MODEL L_EXP=POPUL ROAD TAX VEHIC HOUS / P CLM CLI DW;
  TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
  TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, AND HOUSES VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

PROC REG DATA=EXPEND;
  MODEL L_EXP=POPUL ROAD TAX VEHIC HOUS MILE/ P CLM CLI DW;
  TITLE 'MODEL FOR LOG EXPENDITURES USING REGRESSION INCLUDING';
  TITLE2 'POPULATION, ROADS, TAXS, VEHICLES, HOUSES AND MILES VARIABLES';

PLOT RESIDUAL.*PREDICTED.='*';
RUN;

QUIT;
```

The following file is to find the significance of adding waste materials and by-products to substitute the conventional materials. The two tested hypothesis are: the null hypothesis which indicates that adding waste materials and overall operations costs are independent, versus the alternative hypothesis that support dependancy between adding wastes to the overall costs. The same procedure is repeated to find the significance of adding wastes and byproducts to the engineering performance of the final product.

```
/* THIS FILE IS TO ILLUSTRATE THE FREQUENCY OF USING EACH WASTE MATERIAL
  IN HIGHWAY CONSTRUCTION                              */
/* THE OUTPUT OF THIS FILE CONTAINS THE CHI SQUARE TEST, WHICH TEST THE
ASSOCIATION
  BETWEEN THE TYPE OF WASTE AND THE OVERALL COST              */
OPTION LS=76;
DATA;INPUT TYPE $ COST $ COUNT; CARDS;
RECL_ASPH   MORE  0
RECL_ASPH   EQUAL 6
RECL_ASPH   LESS  28
SCRAP_TIRES  MORE  17
SCRAP_TIRES  EQUAL 0
SCRAP_TIRES  LESS  0
BLAST_SLAG  MORE  1
BLAST_SLAG  EQUAL 11
BLAST_SLAG  LESS  3
STEEL_SLAG  MORE  3
STEEL_SLAG  EQUAL 4
STEEL_SLAG  LESS  2
BOTTOM_ASH  MORE  2
BOTTOM_ASH  EQUAL 3
BOTTOM_ASH  LESS  1
FLY_ASH    MORE  2
FLY_ASH    EQUAL 9
FLY_ASH    LESS  20
COMBS_ASH   MORE  0
COMBS_ASH   EQUAL 0
COMBS_ASH   LESS  1
MINING_WASTE MORE  1
MINING_WASTE EQUAL 3
MINING_WASTE LESS  3
MOTOR_OIL   MORE  0
MOTOR_OIL   EQUAL 0
MOTOR_OIL   LESS  2
BUILD_RUBB  MORE  0
BUILD_RUBB  EQUAL 1
BUILD_RUBB  LESS  5
WASTE_GLASS  MORE  4
WASTE_GLASS  EQUAL 4
WASTE_GLASS  LESS  2
WASTE_PAPER  MORE  0
WASTE_PAPER  EQUAL 1
WASTE_PAPER  LESS  0
ROOF_SHINGL  MORE  0
ROOF_SHINGL  EQUAL 2
ROOF_SHINGL  LESS  4
PLASTICS   MORE  2
PLASTICS   EQUAL 0
PLASTICS   LESS  1
REC_PC     MORE  1
REC_PC     EQUAL 0
REC_PC     LESS  0
```

```
OTHERS     MORE 0
OTHERS     EQUAL 1
OTHERS     LESS 2

PROC FREQ;
TABLES TYPE*COST/EXPECTED CHISQ CELLCHI2;
WEIGHT COUNT;
TITLE 'USING DIFFERENT WASTE MATERIALS BY HIGHWAY AGENCIES';
RUN;
QUIT;

/********************************************************************/
/********************************************************************/

/* THIS FILE IS TO ILLUSTRATE THE FREQUENCY OF USING EACH WASTE MATERIAL
  IN HIGHWAY CONSTRUCTION                                    */
OPTION LS=76;
DATA;INPUT TYPE $ PERFO $ COUNT; CARDS;
RECL_ASPH     BETTER  1
RECL_ASPH     EQUAL   32
RECL_ASPH     WORSE   I
SCRAP_TIRES   BETTER  2
SCRAP_TIRES   EQUAL   8
SCRAP_TIRES   WORSE   7
BLAST_SLAG    BETTER  4
BLAST_SLAG    EQUAL   9
BLAST_SLAG    WORSE   1
STEEL_SLAG    BETTER  5
STEEL_SLAG    EQUAL   2
STEEL_SLAG    WORSE   2
BOTTOM_ASH    BETTER  0
BOTTOM_ASH    EQUAL   5
BOTTOM_ASH    WORSE   1
FLY_ASH      BETTER  I0
FLY_ASH      EQUAL   19
FLY_ASH      WORSE   2
COMBS_ASH     BETTER  0
COMBS_ASH     EQUAL   0
COMBS_ASH     WORSE   I
MINING_WASTE   BETTER  2
MINING_WASTE   EQUAL   4
MINING_WASTE   WORSE   1
MOTOR_OIL     BETTER  0
MOTOR_OIL     EQUAL   2
MOTOR_OIL     WORSE   0
BUILD_RUBB    BETTER  0
BUILD_RUBB    EQUAL   5
BUILD_RUBB    WORSE   I
WASTE_GLASS   BETTER  0
WASTE_GLASS   EQUAL   I0
WASTE_GLASS   WORSE   0
WASTE_PAPER   BETTER  0
WASTE_PAPER   EQUAL  0
WASTE_PAPER   WORSE  1
ROOF_SHINGL   BETTER 0
ROOF_SHINGL   EQUAL  6
ROOF_SHINGL   WORSE  0
PLASTICS      BETTER 1
PLASTICS      EQUAL  1
PLASTICS      WORSE  0
REC_PC        BETTER 0
REC_PC        EQUAL  3
REC_PC        WORSE  0
OTHERS        BETTER 0
OTHERS        EQUAL  0
OTHERS        WORSE  1

PROC FREQ;
TABLES TYPE*PERFO/EXPECTED CHISQ CELLCHI2;
WEIGHT COUNT;
TITLE 'USING DIFFERENT WASTE MATERIALS BY HIGHWAY AGENCIES';
RUN;
QUIT;
```

The following input file is to find the frequency of using waste and by-product materials in different pavement courses.

```
/* THIS FILE IS TO ILLUSTRATE THE FREQUENCY OF USING  WASTE MATERIALS
  IN EACH COURSE IN HIGHWAY CONSTRUCTION                              */
OPTION LS=76;
DATA;INPUT TYPE $ COURSE $ COUNT; CARDS;
RECL_ASPH     FRICT   11
RECL_ASPH     STRUC   32
RECL_ASPH     POR_CEM  I
RECL_ASPH     PAV_BAS  23
RECL_ASPH     SUBGRAD  6
SCRAP_TIRES   FRICT   7
SCRAP_TIRES   STRUC   9
SCRAP_TIRES   POR_CEM  0
SCRAP_TIRES   PAV_BAS  0
SCRAP_TIRES   SUBGRAD  5
BLAST_SLAG    FRICT   7
BLAST_SLAG    STRUC   7
BLAST_SLAG    POR_CEM  9
BLAST_SLAG    PAV_BAS  8
BLAST_SLAG    SUBGRAD  5
STEEL_SLAG    FRICT   7
STEEL_SLAG    STRUC   I
STEEL_SLAG    POR_CEM  1
STEEL_SLAG    PAV_BAS  2
STEEL_SLAG    SUBGRAD  2
BOTTOM_ASH    FRICT   2
BOTTOM_ASH    STRUC   1
BOTTOM_ASH    POR_CEM  1
BOTTOM_ASH    PAV_BAS  4
BOTTOM_ASH    SUBGRAD  3
FLY_ASH       FRICT   3
FLY_ASH       STRUC   3
FLY_ASH       POR_CEM  28
FLY_ASH       PAV_BAS  9
FLY_ASH       SUBGRAD  I0
COMBS_ASH     FRICT   0
COMBS_ASH     STRUC   0
COMBS_ASH     POR_CEM  0
COMBS_ASH     PAV_BAS  0
COMBS_ASH     SUBGRAD  1
MINING_WASTE  FRICT   4
MINING_WASTE  STRUC   4
MINING_WASTE  POR_CEM  2
MINING_WASTE  PAV_BAS  2
MINING_WASTE  SUBGRAD  3
MOTOR_OIL     FRICT   2
MOTOR_OIL     STRUC   I
MOTOR_OIL     POR_CEM  0
MOTOR_OIL     PAV_BAS  0
MOTOR_OIL     SUBGRAD  0
BUILD_RUBB    FRICT   0
BUILD_RUBB    STRUC   0
BUILD_RUBB    POR_CEM  0
BUILD_RUBB    PAV_BAS  3
BUILD_RUBB    SUBGRAD  4
WASTE_GLASS   FRICT    1
WASTE_GLASS   STRUC    4
WASTE_GLASS   POR_CEM  0
WASTE_GLASS   PAV_BAS  5
WASTE_GLASS   SUBGRAD  5
WASTE_PAPER   FRICT    0
WASTE_PAPER   STRUC    0
WASTE_PAPER   POR_CEM  0
WASTE_PAPER   PAV_BAS  1
WASTE_PAPER   SUBGRAD  0
ROOF_SHINGL   FRICT    3
ROOF_SHINGL   STRUC    5
ROOF_SHINGL   POR_CEM  0
ROOF_SHINGL   PAV_BAS  0
ROOF_SHINGL   SUBGRAD  0
PLASTICS      FRICT    0
PLASTICS      STRUC    3
PLASTICS      POR_CEM  0
PLASTICS      PAV_BAS  0
PLASTICS      SUBGRAD  0
REC_PC        FRICT    0
REC_PC        STRUC    2
REC_PC        POR_CEM  3
REC_PC        PAV_BAS  2
REC_PC        SUBGRAD  0
OTHERS        FRICT    0
OTHERS        STRUC    0
OTHERS        POR_CEM  0
OTHERS        PAV_BAS  0
OTHERS        SUBGRAD  1

PROC FREQ;
TABLES TYPE*COURSE/EXPECTED CHISQ CELLCHI2;
WEIGHT COUNT;
TITLE 'USING DIFFERENT WASTE MATERIALS IN DIFFERENT COURSES';
RUN;
QUIT;
```

BIOGRAPHICAL SKETCH

Ashraf El-Assaly graduated from Port Said Secondary school in June of 1978. He was awarded his Bachelor of Science of Civil Engineering degree by Ain-Shams University of Cairo in 1985. He worked for Timsah Ship-building Co. for six years as a field engineer and project cost analyst.

In August of 1991, he earned a scholarship to the University of Florida at Gainesville in the Coastal and Oceanography Engineering Department, sponsored by the Egyptian Ministry of High Education. In Fall 1993, he joined the Civil Engineering Department for the Master of Science degree.

Mr. El-Assaly obtained his master's degree from the structures department in Spring 1994.

Joining the Doctor of Philosophy program in Fall 1994, Mr. El-Assaly worked as a research assistant for the construction management department.

Mr. El-Assaly is married to the former Azza Eldib, and they have two children, a girl and a boy, Rowan El-Assaly, age seven, and Sameh El-Assaly, age four.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ralph D. Ellis

Ralph D. Ellis, Jr., Chair
Associate Professor of
Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Fazil Najafi

Fazil T. Najafi
Associate Professor of
Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Charles R. Glagola
Assistant Professor of
Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

David Bloomquist
Associate Professor of
Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kaiss Al-Ahmady
Assistant Scientist of
Nuclear and Radiological
Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

D. Max Sheppard
Max Sheppard
Professor of Coastal and
Oceanographic Engineering

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1997

for
Winfred Phillips
Dean, College of Engineering

Karen A. Holbrook
Dean, Graduate School